FINAL

Treatability Study in Support of
Intrinsic Remediation
for the Fire Training Area (Site 3)

Michigan Air National Guard
at W.K. Kellogg Memorial Airport
Battle Creek Michigan

Prepared For

Air Force Center for Environmental Excellence
Technology Transfer Division
Brooks Air Force Base, Texas
San Antonio, Texas

and

110th Tactical Fighter Group
Michigan Air National Guard

20000830 023

September 1999

DTIC QUALITY INSPECTED 4

Walton, Norman

From: Hansen, Jerry E, Mr, HQAFCEE [Jerry.Hansen@HQAFCEE.brooks.af.mil]

Sent: Tuesday, August 08, 2000 10:16 AM

To: 'nwalton@dtic.mil'

Subject: Distribution statement for AFCEE/ERT reports

Norman, This is a followup to our phone call. The eight boxes of reports you received from us are all for unlimited distribution. If you have any questions, you can contact me at DSN 240-4353.

PARSONS

29 September 1999

Mr. Jerry Hansen
Technical Program Manager
AFCEE/ERT
3207 North Road, Bldg. 532
Brooks AFB, TX 78235-5363

Subject: Submittal of the Final Treatability Study in Support of Intrinsic Remediation for the Fire Training Area (Site 3), Michigan Air National Guard, at W.K. Kellogg Memorial Airport, Battle Creek, Michigan (Contract F41624-92-D-8036-0006)

Dear Mr. Hansen:

Enclosed please find two copies of the September 1999 Final Treatability Study (TS) in Support of Intrinsic Remediation for the Fire Training Area (Site 3), Michigan Air National Guard, at W.K. Kellogg Memorial Airport, Battle Creek, Michigan. This report was prepared by Parsons Engineering Science, Inc. (Parsons ES) for the Air Force Center for Environmental Excellence Technology Transfer Division (AFCEE/ERT) and the Michigan Air National Guard.

The intent of the TS was to determine the role of natural attenuation in remediating fuel contamination in groundwater at Fire Training Area Site 3. The draft TS was submitted to AFCEE in March 1995. Comments on the draft TS were received from AFCEE dated April 1995 as reviewed by Mr. Chung Yen and an unspecified author. Comments dated 19 July 1995 also were received from Booz•Allen & Hamilton as reviewed by Mr. Daniel Kraft. Responses to these comments were prepared by Parsons ES and are attached in Appendix F.

In addition, groundwater sample data collected by the US Environmental Protection Agency (USEPA) National Risk Management Research Laboratory (NRMRL) in June 1995 and April 1998 have been evaluated and incorporated into this Final TS as an addendum (Appendix G). Conclusions and recommendations from the addendum were further included in the Final TS Executive Summary.

If you have any questions or comments regarding this package, please do not hesitate to contact me at (303) 831-8100.

Sincerely,

PARSONS ENGINEERING SCIENCE, INC.

Bruce M. Henry, P.G.
Project Manager

Enclosures
c.c.   Capt. F.C. Vollmerhausen – Michigan Air National Guard AFB (two copies)
        Mr. Don Kampbell – USEPA NRMRL (two copies)

FINAL
TREATABILITY STUDY
IN SUPPORT OF
INTRINSIC REMEDIATION (NATURAL ATTENUATION)

for the

FIRE TRAINING AREA (SITE 3)

MICHIGAN AIR NATIONAL GUARD
at
W. K. KELLOGG MEMORIAL AIRPORT
BATTLE CREEK, MICHIGAN

September 1999

Prepared for:

AIR FORCE CENTER FOR ENVIRONMENTAL EXCELLENCE
TECHNOLOGY TRANSFER DIVISION
BROOKS AIR FORCE BASE
SAN ANTONIO, TEXAS

AND

110th TACTICAL FIGHTER GROUP
MICHIGAN AIR NATIONAL GUARD
BATTLE CREEK, MICHIGAN

Prepared by:

Parsons Engineering Science, Inc.
1700 Broadway, Suite 900
Denver, Colorado 80290

EXECUTIVE SUMMARY

This report presents the results of a treatability study (TS) performed by Parsons Engineering Science, Inc. (Parsons ES) at the Michigan Air National Guard facility at W. K. Kellogg Memorial Airport, Battle Creek, Michigan to evaluate the use of intrinsic remediation (natural attenuation) with long-term monitoring (LTM) as a remedial option for dissolved benzene, toluene, ethylbenzene, and xylene (BTEX) contamination in the shallow saturated zone in the vicinity of the Fire Training Area (Site 3). Soil and groundwater contamination is documented for the site in this report. Contamination is present as residual light nonaqueous-phase liquid (LNAPL) sorbed to the aquifer matrix, as dissolved constituents in groundwater, and as vapor in the unsaturated zone. There is no evidence of mobile LNAPL (free product) at this site. This study focused on the impact of dissolved BTEX on the shallow groundwater system at the site. Site history and the results of soil and groundwater investigations conducted previously are also summarized in this report.

Comparison of BTEX, electron acceptor, and biodegradation byproduct isopleth maps for Site 3 provides strong evidence that the BTEX compounds dissolved in groundwater are being biodegraded. Geochemical data strongly suggest that biodegradation of fuel hydrocarbons is occurring at the site via aerobic respiration and the anaerobic processes of denitrification, iron reduction, sulfate reduction, and methanogenesis. In addition, patterns in the observed distribution of hydrocarbons, electron acceptors, and biodegradation byproducts provide additional indications that biodegradation is reducing dissolved BTEX concentrations in site groundwater.

An important component of this study was an assessment of the potential for BTEX contamination dissolved in groundwater to migrate from the source area to potential receptors. The Bioplume II model was used to estimate the rate and direction of dissolved BTEX movement through the shallow saturated zone under the influence of advection, dispersion, sorption, and biodegradation. Input parameters for the Bioplume II model were obtained from existing site characterization data, supplemented with data collected by Parsons ES under this program. Extensive site-specific data were used for model implementation. Model parameters that were not measured at the site were estimated using reasonable literature values.

Additional groundwater data collected in June 1995 and April 1998 confirm that the rate of BTEX loading to groundwater appears to be decreasing due to natural attenuation and bioventing, and that dissolved BTEX concentrations in groundwater are generally decreasing, as predicted by the Bioplume II simulations. Temporal data for BTEX concentrations from monitoring wells/points at Site 3 confirms a decrease in the source area. However, there are insufficient data to determine temporal changes in the extent of the downgradient portion of the BTEX plume.

Results of the June 1995 and April 1998 sampling events also continue to support the occurrence of natural attenuation of remaining dissolved BTEX at Site 3. However, as a result of decreasing fuel hydrocarbon concentrations, microbial activity in the groundwater appears to be diminishing, as evidenced by increases in groundwater

oxidation-reduction potential (ORP) and dissolved oxygen (DO) concentrations, and decreasing ferrous iron concentrations.

The results of this study suggest that dissolved BTEX contamination present in groundwater poses no significant threat to human health or the environment in its present, or predicted future, concentrations and distributions. Parsons ES therefore recommends that intrinsic remediation with LTM be implemented for dissolved BTEX contamination found in groundwater at this site.

To verify the Bioplume II model predictions, Parsons ES recommends using five LTM wells (two of which comprise a nested well pair) and four point-of-compliance (POC) monitoring wells (two of which comprise a nested well pair) to monitor the long-term migration and degradation of the dissolved BTEX plume. Regular sampling and analysis of groundwater from these sampling points will allow the effectiveness of intrinsic remediation to be monitored and should allow sufficient time to implement engineering controls to contain the plume if BTEX compounds are detected in the POC wells. The proposed remediation alternative based on the contaminant fate and transport model results suggest that these wells should be sampled on an annual basis for 12 years. Along with other analyses used to verify the effectiveness of intrinsic remediation, the groundwater samples should be analyzed for BTEX compounds by USEPA Method SW8020. If BTEX concentrations in groundwater from the POC wells exceed the Michigan Generic Type B cleanup criteria of 1.2 micrograms per liter (µg/L) for benzene, 790 µg/L for toluene, 74 µg/L for ethylbenzene, or 280 µg/L for total xylenes, additional corrective actions may be required to remediate groundwater at the site.

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ACRONYMS AND ABBREVIATIONS

AFCEE	Air Force Center for Environmental Excellence
ANGRC	Air National Guard Readiness Center
atm-m^3/mol	atmosphere-cubic meter per mole
bgs	below ground surface
BTEX	benzene, toluene, ethylbenzene, and xylenes
°C	degrees Celsius
CPT	HAZWRAP
DO	dissolved oxygen
ES	Engineering-Science, Inc.
ft/day	feet per day
ft^2/day	square feet per day
ft/ft	foot per foot
ft/sec	feet per second
ft/yr	feet per year
g/ml	grams per milliliter
HAZWRAP	Hazardous Waste Remedial Actions Program
HDPE	high-density polyethylene
ID	inside diameter
IRP	Installation Restoration Program
K$_{oc}$	soil sorption coefficient
LIF	laser induced fluorometry
LNAPL	light nonaqueous-phase liquid
LTM	long-term monitoring
MANG	Michigan Air National Guard
MDNR	Michigan Department of Natural Resources
mg/kg	milligrams per kilogram
mm Hg	millimeters of mercury
MOC	Method of Characteristics
msl	mean sea level
mV	millivolts
OD	outside diameter
Parsons ES	Parsons Engineering Science, Inc.
PCE	tetrachloroethene
POC	point of compliance
ppmv	parts per million by volume
PVC	polyvinyl chloride
RAOs	remedial action objectives
redox	reduction/oxidation
RMS	root mean squared
RSKERL	Robert S. Kerr Environmental Research Laboratory
SAP	Sampling and Analysis Plan
SI	site investigation
TCE	trichloroethene

TMB	trimethylbenzene
TOC	total organic carbon
TPH	total petroleum hydrocarbon
TRPH	total recoverable petroleum hydrocarbon
TS	Treatability Study
TVH	total volatile hydrocarbon
µg/L	micrograms per liter
USACE	United States Army Corps of Engineers
USEPA	United States Environmental Protection Agency
USGS	United States Geologic Survey
VOC	volatile organic compound

SECTION 1

INTRODUCTION

This treatability study (TS) was prepared by Parsons Engineering Science, Inc. (Parsons ES) [formerly Engineering-Science, Inc. (ES)] and presents the results of the collection, evaluation, and interpretation of data conducted to evaluate the use of intrinsic remediation (natural attenuation) with long-term monitoring (LTM) for remediation of fuel-hydrocarbon-contaminated groundwater at the Fire Training Area (Site 3), at the Michigan Air National Guard (MANG) facility (hereafter referred to as the Base) at W. K. Kellogg Memorial Airport in Battle Creek, Michigan. Previous investigations determined that mixtures of waste JP-4, waste oils, waste hydraulic fluid, and spent cleaning solvents burned during fire training exercises were the source of contamination released into the soil and shallow groundwater at the site. The main emphasis of the work described herein was to evaluate the potential for naturally occurring degradation mechanisms to reduce dissolved benzene, toluene, ethylbenzene, and xylene (BTEX) concentrations in groundwater to levels that are protective of human health and the environment.

1.1 SCOPE AND OBJECTIVES

Parsons ES, in conjunction with researchers from the United States Environmental Protection Agency (USEPA) Robert S. Kerr Environmental Research Laboratory (RSKERL), was retained by the United States Air Force Center for Environmental Excellence (AFCEE) to conduct site characterization and groundwater modeling in support of intrinsic remediation (natural attenuation) with long-term monitoring.

The scope of work for this project involved the following tasks:

- Reviewing existing hydrogeologic and soil and groundwater quality data for the site;

- Conducting supplemental site characterization activities to determine the nature and extent of soil and groundwater contamination and to collect geochemical data in support of intrinsic remediation;

- Developing a conceptual hydrogeologic model of the shallow saturated zone, including the current distribution of contaminants and probable contaminant migration pathways;

- Determining if natural processes of contaminant destruction are occurring in groundwater at the site;

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- Performing contaminant fate and transport modeling based on site hydrogeologic conditions using the Bioplume II model;

- Evaluating a range of model input parameters to determine the sensitivity of the model to those parameters and to consider several contaminant fate and transport scenarios;

- Determining if naturally occurring processes are sufficient to minimize BTEX plume expansion so that groundwater quality standards can be met at a downgradient point of compliance (POC);

- Conducting a preliminary pathway analysis for fuel hydrocarbon contamination in groundwater;

- Developing remedial action objectives (RAOs) and reviewing available remedial technologies;

- Using the results of modeling to recommend the most appropriate remedial option based on specific effectiveness, implementability, and cost criteria; and

- Providing an LTM plan that includes LTM and POC well locations and a sampling and analysis plan (SAP).

Site characterization activities in support of intrinsic remediation included soil sample collection and analysis, groundwater monitoring point installation using the cone penetrometer, and sampling and analysis of groundwater from newly installed and existing monitoring wells and points. Additional groundwater monitoring was performed by the USEPA Natural Risk Management Research Laboratory (NRMRL, formerly the RSKERL) in June 1995 and April 1998. Data from these sampling events were not available for analysis in preparation of this TS, but have been analyzed in an addendum to this TS (Appendix G).

Site-specific data were used to develop a fate and transport model for the site using Bioplume II and to conduct a preliminary exposure assessment. The Bioplume II model was used to simulate the movement and degradation of BTEX in the shallow saturated zone under the influence of advection, dispersion, sorption, and biodegradation. As part of the TS, this modeling effort had three primary objectives: 1) to predict the future extent and concentration of a dissolved contaminant plume by modeling the combined effects of advection, dispersion, sorption, and biodegradation; 2) to assess the possible risk to potential downgradient receptors by conducting a preliminary exposure assessment; and 3) to provide technical support for the intrinsic remediation with LTM remedial option at regulatory negotiations, as appropriate.

Bioventing and natural contaminant attenuation with LTM were among the remedial technologies evaluated during this TS. All hydrogeologic and groundwater chemical data necessary to evaluate these remedial options were collected under this program; however, the field work conducted under this program was oriented toward the collection of hydrogeologic data to be used as input into the Bioplume II groundwater model in support of intrinsic remediation with LTM for restoration of fuel hydrocarbon contaminated groundwater.

1-2

This report contains 11 sections, including this introduction, and seven appendices. Section 2 summarizes site characterization activities. Section 3 summarizes the physical characteristics of the study area. Section 4 describes the nature and extent of soil and groundwater contamination and the geochemistry of soil and groundwater at the site. Section 5 describes the Bioplume II model and design of the conceptual model for the site, lists model assumptions and input parameters, and describes sensitivity analyses, model output, and the results of the Bioplume II modeling. Section 6 presents a comparative analysis of remedial alternatives. Section 7 presents the LTM plan for the site. Section 8 presents the conclusions of this work and provides recommendations for further work at the site. Section 9 lists the references used to develop this document. Appendix A contains cone penetrometer logs, monitoring point completion diagrams, and aquifer test results. Appendix B presents soil and groundwater analytical results. Appendix C contains model input and calculations related to model calibration. Appendix D contains Bioplume II model results in ASCII format on a diskette. Appendix E contains remedial alternative cost calculations. Appendix F contains responses to comments on the draft TS. Appendix G contains an addendum to this treatability study which documents the effectiveness of natural attenuation at the site by summarizing results from two recent (June 1995 and April 1998) groundwater sampling events.

1.2 Facility Background

The Base is in the northwestern portion of the W.K. Kellogg Regional Airport in Battle Creek, Michigan (Figure 1.1). Site 3 is located in the western section of the Base and is approximately 500 feet north of the northwestern end of the southeast-northwest runway (Figure 1.2).

1.2.1 Operational History

Fire training exercises were conducted at Site 3 from approximately 1977 to 1986. A total of approximately 54,000 to 74,000 gallons of a mixture of waste JP-4, waste oils, waste hydraulic fluid, and spent cleaning solvents were reportedly burned during fire training exercises (ES, 1993). In the burn pit, the wastes were floated on top of water, ignited, then extinguished. Immediately north of the pit, drums of the wastes were stored before use in fire training exercises (Figure 1.2).

Installation Restoration Program (IRP) action was initiated at the Base in 1988, when the Air National Guard Readiness Center (ANGRC) and the Hazardous Waste Remedial Actions Program (HAZWRAP) retained ES to conduct a site investigation (SI) for six disposal/spill sites at the Base. IRP SI work at the Base began in 1988, and consisted of monitoring well installation and collection and analysis of groundwater, soil, sediment, and surface water samples at five of six sites, including Site 3. In 1989, additional wells were installed at Site 3 and along the northern and western Base boundary, and groundwater samples were collected from all existing wells. In 1991, groundwater samples from all existing monitoring wells were collected and analyzed, and additional soil and surface water samples were collected from some locations (ES, 1993). Data gathered during the 1988, 1989, and 1991 investigations is presented in the Work Plan (Parsons ES, 1994) and in the Treatability Study Addendum (Appendix G).

1-3

MICHIGAN

110th TASG
MICHIGAN AIR
NATIONAL GUARD

C A L H O U N   C O U N T Y
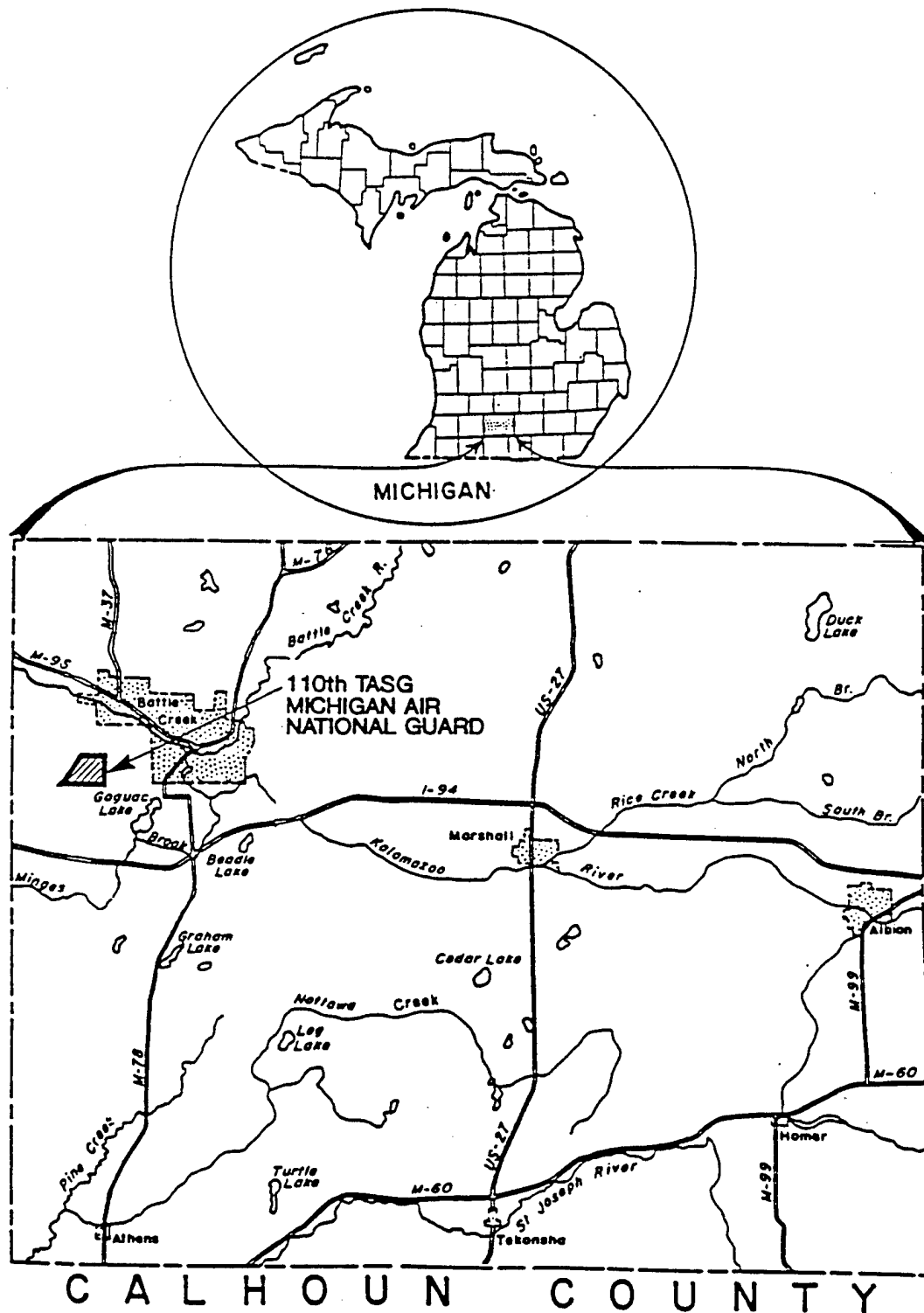
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FIGURE 1.1

REGIONAL LOCATION MAP

Site 3 (Fire Training Area)
Intrinsic Remediation TS
Michigan Air National Guard, W.K. Kellogg Airport
Battle Creek, Michigan

**PARSONS
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Denver, Colorado

SOURCE: VanLier, 1966.

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LEGEND

IRP Site & Number

-------- Installation Boundary

SITE 2

SITE 1

SITE 5

SITE 6

SITE 3

SITE 4

6900

6905

6914

6910

SCALE

0   700

FEET

FIGURE 1.2

SITE LOCATION

Site 3 (Fire Training Area)
Intrinsic Remediation TS
Michigan Air National Guard, W.K. Kellogg Airport
Battle Creek, Michigan

PARSONS
ENGINEERING SCIENCE, INC.

Denver, Colorado

SOURCE: ES 1993.
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Results of the SI indicated the presence of dissolved fuel hydrocarbons and chlorinated solvents in the groundwater beneath and downgradient of the burn pit. Soil contamination was also detected, but during data validation, the laboratory data for soil were qualified as unusable and rejected. The results of soil sampling were therefore used only in a qualitative sense to infer the presence of soil contamination. A final report documenting the results of the SI work was submitted in November 1993 (ES, 1993).

1.2.2 Current Remedial Activities

A pilot-scale bioventing system is currently in place at Site 3 to address the soil contamination in the central portion of the bermed fire pit. Initial results from this pilot test have been promising, indicating excellent biodegradation rates and significant reductions of BTEX compounds in the soils within the 50-foot treatment radius of the pilot vent well. Details regarding this system are presented in a work plan and interim results report (ES, 1992).

SECTION 2

SITE CHARACTERIZATION ACTIVITIES

This section presents the methods used by Parsons ES and EPA RSKERL personnel to collect physical and chemical data in support of this TS for Site 3 at the Base. Most of the soil, groundwater, and geologic data collection during the field study was accomplished using cone penetrometry testing (CPT) technology. Exploratory punches with the cone penetrometer apparatus were used to help define soil stratigraphy, to collect soil samples for analysis, and to delineate the extent of fuel contamination in the vadose zone. Screened piezometers were installed with the CPT apparatus for collection of groundwater samples and groundwater elevation data. Groundwater samples and water level elevation data were also collected from monitoring wells installed during previous site investigations. Hydrogeologic characteristics of the shallow aquifer in the vicinity of Site 3 were defined by interpretation of data obtained from aquifer slug tests performed in existing wells at the site.

Data collected from the field study were integrated with previously collected data to develop a conceptual site model of the physical setting (Section 3) and the contaminant distribution (Section 4) at Site 3. The physical and chemical hydrogeologic data collected during the field work phase of this TS are listed below:

- Depth from measurement datum to the water table or potentiometric surface in monitoring wells and monitoring points;

- Location of potential groundwater recharge and discharge areas;

- Hydraulic conductivity as determined through slug tests;

- Stratigraphic analysis of subsurface media;

- Estimation of extent and thickness (or lack thereof) of free-phase product;

- Dissolved oxygen (DO), nitrate, ferrous iron, sulfate, chloride, and total organic carbon (TOC) concentrations in groundwater;

- Temperature, specific conductivity, reduction/oxidation (redox) potential, total alkalinity, and pH of groundwater;

- BTEX and trimethylbenzene (TMB) concentrations in groundwater; and

- BTEX and TMB concentrations in soil.

2-1

The following sections describe the procedures that were followed during the field investigation. CPT, soil sampling, and groundwater monitoring point installation and development procedures are described in Section 2.1. Procedures for sampling existing monitoring wells and newly installed monitoring points are described in Section 2.2. Aquifer testing procedures are described in Section 2.3.

2.1 CONE PENETROMETRY, MONITORING POINT INSTALLATION, AND SOIL SAMPLING ACTIVITIES

CPT-related activities took place between August 17 and August 23, 1994. Soil sampling and groundwater monitoring point installation were accomplished using the procedures described in the following sections. Parsons ES field personnel observed all CPT and monitoring point installation activities and maintained a log documenting any unusual conditions encountered during installation. The US Army Corps of Engineers (USACE) also kept logs of penetrometer refusal depths and the order of sampling. Final CPT logs are presented in Appendix A.

Cone penetrometry is an expeditious and effective means of analyzing subsurface stratigraphy by measuring the resistance of different soil types against the conical probe of the penetrometer as it is pushed into the ground. A diagram of the penetrometer rod and tip assembly is shown in Figure 2.1. The measured resistance on the pressure tip and friction sleeves on the side of the cone penetrometer rod are correlated to soil cores collected to calibrate the CPT readings to the lithologies present at the site. Highly resistant lithologies, such as layers of cobbles or highly compacted silt, can damage the penetrometer/ laser induced fluorometry (LIF) apparatus. Such damage was incurred at Site 3 due to gravel and cobble layers at two depths. As a result, neither CPT lithology measurements nor detection of soil contamination by LIF were obtained from this study. Soil stratigraphy was defined by recording depths of refusal of the penetrometer pushrod at gravel/cobble layers and by discrete soil sampling with a Hoggen Toggler® attachment. Methodologies for the collection of soil core data are described in Section 2.1.3.

Further reference to CPT testing in this report signifies the use of the cone penetrometer tip and apparatus for the placement of monitoring points and the collection of soil samples. Such reference does not signify the collection of electronically generated lithology or LIF data. For this TS, ESSB designates a soil sampling location completed by Parsons ES in August 1994; ESMP designates a monitoring point location completed by Parsons ES in August 1994; and MW designates the location of an monitoring well completed by ES in 1988-1989.

CPT was applied using the USACE cone penetrometer truck, which consists of an instrumented probe that is forced into the ground using a hydraulic load frame mounted on a truck, with the weight of the truck providing the necessary reaction mass. The penetrometer equipment is mounted inside an 18-foot van body on a 10-wheel truck chassis with a turbo-charged diesel engine. Ballast in the form of metal weights and a steel water tank, which can hold 5,000 pounds of water, is added to the truck to achieve an overall push capability of 45,000 pounds. Penetration force is supplied by a pair of large hydraulic cylinders bolted to the truck frame.

2-2

Flush Threaded Sch 40
Blank PVC

Penetrometer Push Rod
1.8" OD/0.8" ID

0.01" Slotted
Sch 40 PVC, 0.5" ID

2" OD Stainless Steel
Sacrificial Tip

Tip Stress
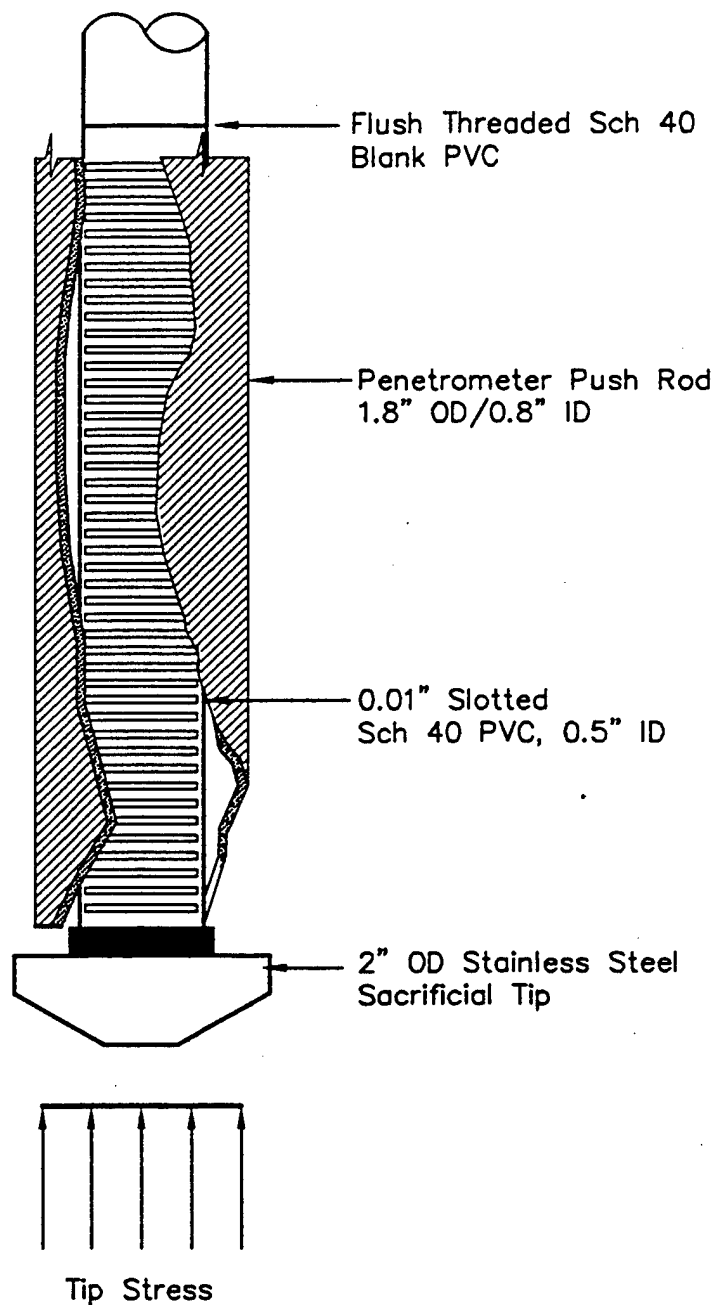
NOT TO SCALE

FIGURE 2.1

**SCHEMATIC OF
CONE PENETROMETER ROD**

Site 3 (Fire Training Area)
Intrinsic Remediation TS
Michigan Air National Guard, W.K. Kellogg Airport
Battle Creek, Michigan

**PARSONS
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Denver, Colorado

The penetrometer probe used was of standard dimensions, having a 1.8-inch outer diameter (OD), 60-degree conical tip, and a 1.8-inch OD by 5.27-inch-long friction sleeve. The penetrometer was advanced vertically into the soil at a constant rate of 48 inches per minute, although this rate was sometimes reduced depending on the resistance of the soils encountered. Monitoring points were placed with the penetrometer apparatus by placing 0.5-inch inner diameter (ID) polyvinyl chloride (PVC) blank and screened casing within the hollow center of the penetrometer rod, and inserting the rod to the desired depth. Descriptions of the procedures used for monitoring point placement are presented in Section 2.1.2.

2.1.1 CPT Sampling Locations

CPT groundwater and/or soil sampling was performed at 22 locations at Site 3. This included 13 monitoring point locations (ESMP-1 through -13) and 9 separate soil boreholes (ESSB-1 through -10). ESMP-1 (ESSB-6) was the only monitoring point location which included the collection of a soil sample during installation. Of 18 locations initially selected for monitoring point placement, only 13 locations were viable because of the presence of a highly resistive layer of cobbles near the water table. This layer was most commonly encountered in the vicinity of the fire-training pit, and it is described in greater detail in Section 3.3.1. Monitoring point locations are illustrated on Figure 2.2. A total of 25 screened intervals were placed in the 13 monitoring point locations, with 11 locations containing multiple screens for greater resolution of vertical groundwater contamination. Table 2.1 presents details regarding CPT-related activity undertaken at each location. Each monitoring point location was selected to provide the groundwater data suitable for evaluation of natural attenuation.

2.1.2 Groundwater Monitoring Point Installation Procedures

This section describes the procedures and equipment used for installation of new groundwater monitoring points with the CPT apparatus.

2.1.2.1 Pre-Installation Activities

All necessary digging, drilling, and groundwater monitoring well installation permits were obtained prior to field mobilization. In addition, all utility lines were located, and proposed drilling locations were cleared with appropriate Base personnel prior to any drilling activities

2.1.2.2 Equipment Decontamination Procedures

After sampling at each CPT location, CPT pushrods were cleaned with the USACE's CPT steam-cleaning system (rod cleaner) as the rods were withdrawn from the ground. A vacuum system located beneath the CPT truck was used to recover cleaning water. Use of this system resulted in nearly 100-percent recovery of steam-cleaning rinseate from the rod cleaner. Rinseate was generated only as the rods moved past the cleaner, thereby minimizing liquid waste generation. Rinseate was collected in 55-gallon drums provided by the USACE and disposed of in on-Base industrial drains as directed by Base personnel.
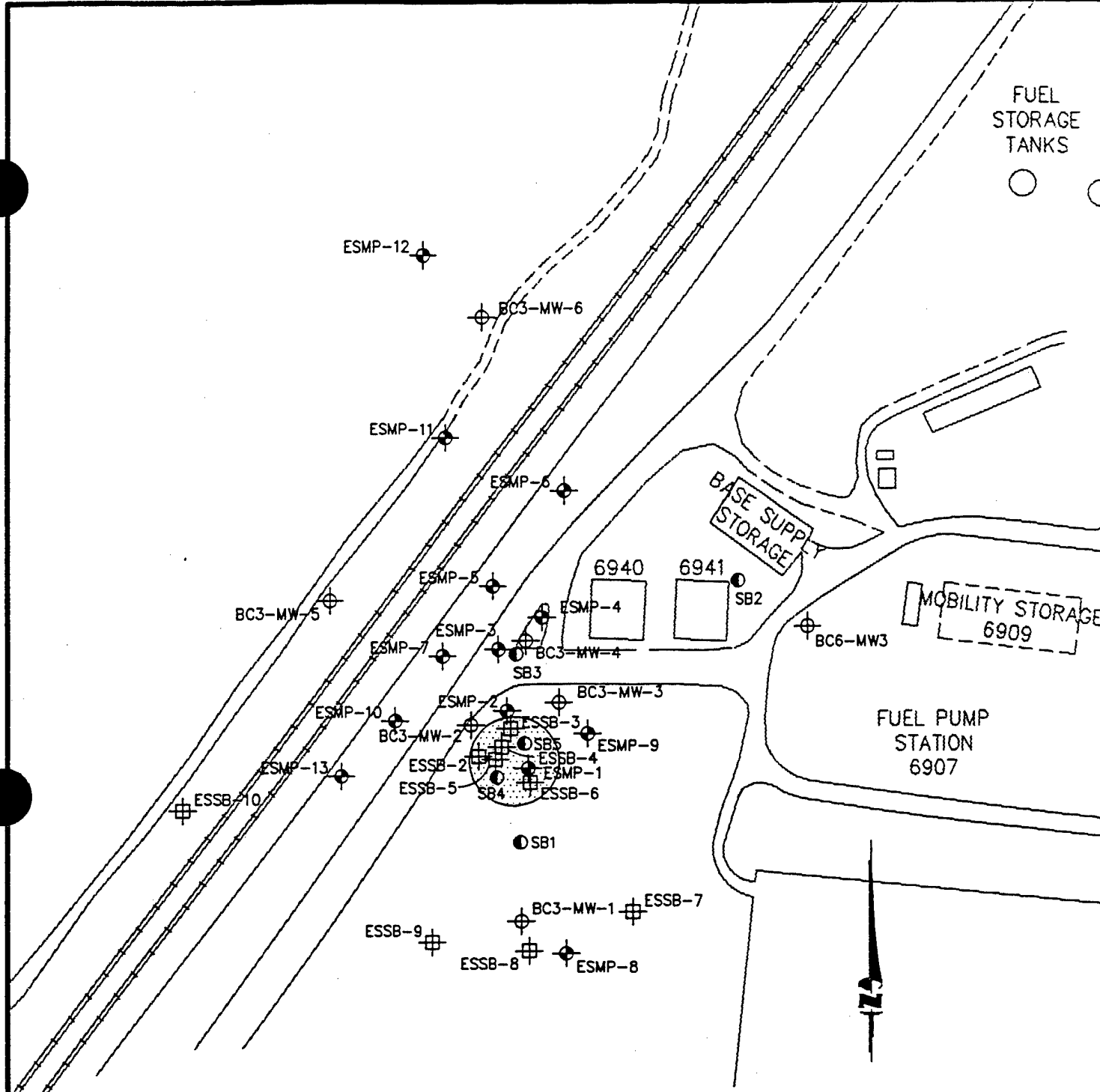
LEGEND

ESMP-1 MONITORING POINT (August, 1994)

ESSB-1 SOIL BOREHOLE (August, 1994)

BC3-MW-1 MONITORING WELL (1988-1989)

SB1 SOIL BORING (1988-1989)

FIRE TRAINING AREA

150 0 75   0   150
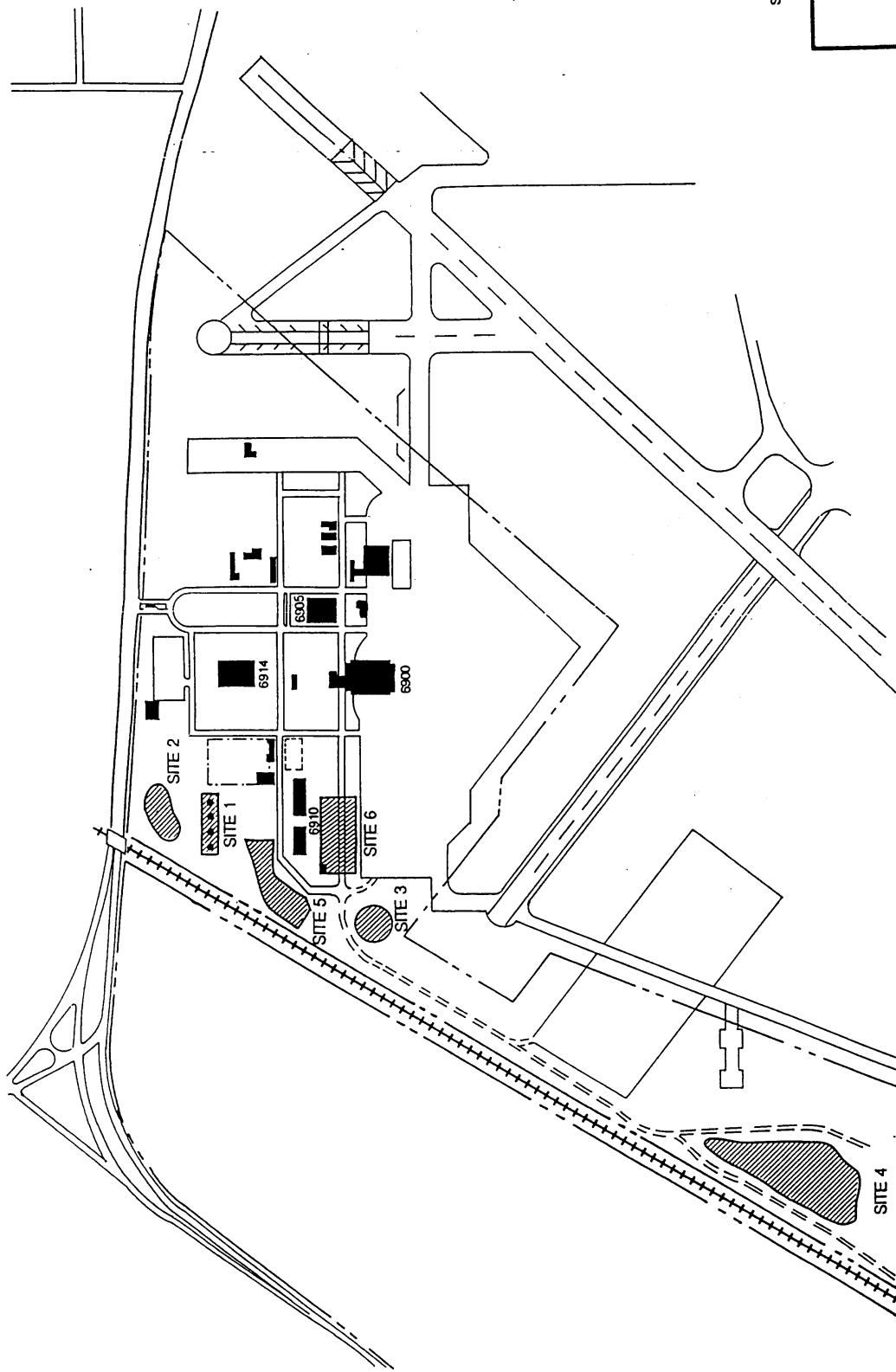
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FIGURE 2.2

MONITORING POINT, SOIL BORING
AND MONITORING WELL LOCATIONS

Site 3 (Fire Training Area)
Intrinsic Remediation TS
Michigan Air National Guard, W.K. Kellogg Airport
Battle Creek, Michigan

PARSONS
ENGINEERING SCIENCE, INC.

Denver, Colorado

TABLE 2.1
MONITORING POINT AND EXISTING WELL COMPLETION DETAILS
SITE 3 (FIRE TRAINING AREA) INTRINSIC REMEDIATION TS
MICHIGAN AIR NATIONAL GUARD
W.K. KELLOGG MEMORIAL AIRPORT
BATTLE CREEK, MICHIGAN

Location	Installation Date	Westing[a]	Northing[a]	Datum Elevation[b] (ft msl)[c]	Ground Elevation (ft msl)	PVC Casing ID (inches)	Screen Length (feet)	Total Depth (ft btoc)[d]	Depth to Top of Screen (ft btoc)	Depth to Base of Screen (ft btoc)
ESMP-1S	8/19/94	5.02	-76.02	919.10	NA[e]	0.50	3.28	31.16	27.88	31.16
ESMP-1D	8/19/94	3.61	-76.81	919.09	NA	0.50	3.28	44.17	40.89	44.17
ESMP-2S	8/19/94	47.05	-27.48	918.54	NA	0.50	3.28	33.20	29.92	33.20
ESMP-2D	8/19/94	47.77	-28.50	918.48	NA	0.50	3.28	43.79	40.51	43.79
ESMP-3S	8/19/94	78.60	29.61	918.20	NA	0.50	3.28	30.40	27.12	30.40
ESMP-3D	8/19/94	80.89	28.46	918.24	NA	0.50	3.28	43.26	39.98	43.26
ESMP-3DD	8/20/94	80.08	29.59	918.14	NA	0.50	3.28	56.29	53.01	56.29
ESMP-4S	8/19/94	48.52	76.90	916.95	917.21	0.50	3.28	29.84	26.56	29.84
ESMP-4D	8/20/94	47.62	75.11	916.83	NA	0.50	3.28	42.90	39.62	42.90
ESMP-5S	8/20/94	107.91	87.98	916.38	NA	0.50	3.28	26.18	22.90	26.18
ESMP-5D	8/20/94	108.19	86.50	916.39	NA	0.50	3.28	39.98	36.70	39.98
ESMP-6S	8/20/94	74.22	208.24	915.39	915.65	0.50	3.28	26.43	23.15	26.43
ESMP-6D	8/20/94	74.63	206.61	915.31	NA	0.50	3.28	40.00	36.72	40.00
ESMP-7S	8/20/94	130.31	2.06	917.10	917.43	0.50	3.28	28.59	25.31	28.59
ESMP-7D	8/20/94	130.81	0.96	917.18	NA	0.50	3.28	40.52	37.24	40.52
ESMP-8S	8/20/94	-77.85	-264.89	921.11	NA	0.50	3.28	31.99	28.71	31.99
ESMP-8D	8/20/94	-79.81	-264.06	920.98	NA	0.50	3.28	45.07	41.79	45.07
ESMP-9S	8/20/94	-39.37	-19.92	918.95	NA	0.50	3.28	28.12	24.84	28.12
ESMP-10S	8/20/94	153.00	-79.25	917.66	917.96	0.50	3.28	27.43	24.15	27.43
ESMP-10D	8/20/94	153.16	-81.13	917.67	NA	0.50	3.28	41.99	38.71	41.99
ESMP-11S	8/21/94	209.19	215.80	911.20	908.15	0.50	3.28	27.79	24.51	27.79
ESMP-11D	8/21/94	209.63	214.45	911.18	NA	0.50	3.28	43.88	40.60	43.88
ESMP-12S	8/21/94	299.43	385.46	914.32	911.97	0.50	3.28	32.49	29.21	32.49
ESMP-12D	8/21/94	300.42	384.46	914.47	NA	0.50	3.28	51.34	48.06	51.34
ESMP-13S	8/21/94	185.69	-154.07	918.72	918.11	0.50	3.28	30.59	27.31	30.59

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3/10/95

TABLE 2.1 (Continued)
MONITORING POINT AND EXISTING WELL COMPLETION DETAILS
SITE 3 (FIRE TRAINING AREA) INTRINSIC REMEDIATION RAP
MICHIGAN AIR NATIONAL GUARD
W.K. KELLOGG MEMORIAL AIRPORT
BATTLE CREEK, MICHIGAN

Location	Installation Date	Westing[a]	Northing[a]	Datum Elevation[b] (ft msl)[c]	Ground Elevation (ft msl)	PVC Casing ID (inches)	Screen Length (feet)	Total Depth (ft btoc)[d]	Depth to Top of Screen (ft btoc)	Depth to Base of Screen (ft btoc)
BC3-MW1	11/88	-35.20	-252.92	923.16	921.90	2	15	42.26	26	41
BC3-MW2	11/88	86.38	-51.96	920.73	919.70	2	15	41.03	24.5	39.5
BC3-MW3	11/88	0	0	920.30	919.40	2	15	40.90	24	39
BC3-MW4	11/88	55.53	48.31	920.42	918.60	2	10	70.32	55	65
BC3-MW5	8/89	294.20	21.49	920.28	918.74	2	15	41.54	22	37
BC3-MW6	8/89	207.97	285.88	913.42	911.92	2	15	35.00	18.5	33.5

[a] Coordinates referenced to BC3-MW3 with northing and westing of this point set to 0 west and 0 north.

[b] Datum elevation and ground elevation are referenced to BC3-MW3, which has a known ground elevation of 919.4 ft msl.

[c] ft msl = feet above mean sea level.

[d] ft btoc = feet below top of casing.

[e] NA = data not available.

I:\45010\tables\TABLE2-1.XLS

Potable water used in CPT equipment cleaning, decontamination, or grouting was obtained from Base water supplies. Water use approval was verified by contacting the appropriate facility personnel. Precautions were taken to minimize any impact to the surrounding area that might result from decontamination operations.

Fuel, lubricants, and other similar substances were handled in a manner consistent with accepted safety procedures and standard operating practices. Well completion materials were not stored near or in areas which could be affected by these substances.

2.1.2.3 Monitoring Point Installation

Groundwater monitoring points (piezometers) were installed at 13 locations under this program. Detailed well installation procedures are described in the following paragraphs. Eleven of the locations contain nested monitoring points screened at different depths. At these locations, the point with the shallowest screened interval was designated with the suffix "S", while the deeper point was designated with the suffix "D" (e.g., ESMP-2S or ESMP-2D). At ESMP-3, monitoring points were installed at three different depths. The monitoring point numbers included the designations "S" for the shallow depth; "D" for the intermediate depth; and "DD" for the deepest depth. Monitoring point completion diagrams are included in Appendix A.

2.1.2.3.1 Monitoring Point Materials Decontamination

Prior to use, all well completion materials were inspected by the field scientist to ensure the suitability of the materials. All well completion materials were factory sealed. Materials deemed unsatisfactory were not used. Materials were inspected for external contamination before use and materials that could not be cleaned to the satisfaction of the field scientist were not used.

2.1.2.3.2 Monitoring Point Screen and Casing

Upon insertion of the CPT rod and cone to the selected termination depth, a monitoring point casing was installed. PVC casing and screen were attached to a sacrificial tip on the downhole end of the penetrometer rod (Figure 2.1). The sacrificial tip was released from the rod at the desired depth and secured into the soil to anchor the screen and riser materials upon extraction of the rod assembly. Construction details were noted on a Monitoring Point Installation Record form. This information became part of the permanent field record for the site and is contained in Appendix A.

Blank monitoring point casing was constructed of Schedule 40 PVC with an ID of 0.5 inch. All monitoring point casing sections were flush-threaded. Glue was not used to secure joints to avoid potential groundwater contamination with solvents. The casing at each monitoring point was fitted with a PVC top cap which was vented to maintain ambient atmospheric pressure within the well casing.

Monitoring point screens were factory slotted with 0.010-inch openings and were constructed of Schedule 40 PVC with an ID of 0.5 inch. The screens were 1 meter long and flush-threaded to the blank casing. The position of the screen was selected by the field hydrogeologist after evaluation of data obtained in the initial CPT push. The total

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depths of the monitoring points and the lengths of all PVC blank and screen used to construct the monitoring points were measured to the nearest 0.1 foot upon completion.

2.1.2.3.3 Flush-Mount Protective Cover

Each monitoring point was completed with an at-grade protective cover. In areas with pavement, the at-grade covers were cemented in place using concrete blended to the existing pavement. All wells were completed with concrete pads that slope gently away from the protective casing to facilitate runoff during precipitation events.

2.1.2.4 Monitoring Point Development

Newly installed monitoring points were developed prior to sampling. Development removes sediment from inside the well casing and flushes fine-grained sediments from the portion of the formation adjacent to the well screen.

Monitoring point development was accomplished using a peristaltic pump. In points with PVC casing, the pump tubing was regularly lowered to the bottom of the monitoring point so that fine-grained sediments were agitated and removed from the well in the development water. Development was continued until a minimum of 10 casing volumes of water were removed from the monitoring point and the pH, temperature, specific conductivity, DO concentration, and redox potential of the groundwater had stabilized. All well development waters were collected in 55-gallon drums and disposed of in appropriate industrial drains on the Base.

2.1.2.5 Water Level Measurements

Water levels were measured at all monitoring points. Measurements were made using an electric water level probe capable of recording to the nearest 0.01 foot. Water levels were measured immediately after monitoring point construction and before development. At the end of the project, water level measurements were collected in monitoring wells and all newly installed monitoring points within a 2-hour interval on August 23, 1994. These data are presented in Section 3.

2.1.2.6 Monitoring Point Location and Datum Survey

The locations and elevations of the new monitoring points were surveyed by USACE personnel after monitoring point completion. The horizontal locations were measured to the nearest foot north and east of existing well BC3-MW3. The vertical location of the adjacent ground surface was measured relative to a US Geological Survey (USGS) mean sea level (msl) datum taken from a previous survey. The ground surface elevation was measured to the nearest 0.01 foot, and the distance from the ground surface to the measurement datum was later measured to the nearest 0.01 foot by hand. Survey results are presented in Table 2.1.

2.1.3 Soil Sampling

Twenty-four soil samples were obtained from 10 CPT holes (including one monitoring point location) using the Hoggen Toggler® sampling device. The sampler is coupled to

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the penetrometer rod and pushed into the soil with the same equipment used for CPT/LIF. While the Hoggen Toggler® cone is in position, soil is prevented from entering the sampling tube until the desired depth is achieved. After the sampler was pushed to the depth at which the soil sample was to be taken, the sampling unit was raised a few inches, and the Hoggen Toggler® apparatus was unlocked. After unlocking the Hoggen Toggler® attachment, a soil section was cut, and the sampling apparatus was pulled from the ground as quickly as possible. The Hoggen Toggler® sampling apparatus allowed collection of an 8-inch-long by 1-inch diameter continuous sample. Recovery efficiencies for samples were high because few were taken in saturated zones where soils have a tendency to drop out of the sampler as the rods are pulled up. Soil samples collected for laboratory analysis were removed from the sampler, placed in clean glass jars, labeled, recorded in the field notebook, and immediately stored at 4 degrees Celsius (°C) for shipment to the onsite USEPA mobile laboratory. Soil sample locations and depths are summarized on Table 2.2. Soil samples were analyzed for aromatic hydrocarbons by method RSKSOP-124 (modified); total organic carbon by methods RSKSOP-102 and -120; moisture by method ASTM D-2216; and total petroleum hydrocarbons by method RSKSOP-174.

All soil sampling tools were cleaned onsite prior to use and between each sampling event with a phosphate-free detergent followed by a potable water rinse. All decontamination activities were conducted in a manner to ensure that the excess water was contained and disposed of properly.

2.2 GROUNDWATER SAMPLING

This section describes the procedures used for collecting groundwater samples for water quality analysis. These procedures were followed in order to maintain a high degree of quality control during the sampling event.

Groundwater samples were collected after installation of monitoring points. Existing wells were sampled by Parsons ES and/or RSKERL personnel while new monitoring points were being installed. Sampling of monitoring wells and points is described in Section 2.2.3.1. Sample analysis was performed by USEPA RSKERL personnel and subcontractors.

Activities that occurred during groundwater sampling are summarized below:

- Assembly and preparation of equipment and supplies;

- Inspection of the well integrity (for monitoring well sampling), including

    - Protective cover, cap and lock,

    - External surface seal and pad,

    - Well stick-up, cap, and datum reference, and

    - Internal surface seal;

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TABLE 2.2
SOIL SAMPLE DESIGNATIONS
SITE 3 (FIRE TRAINING AREA) INTRINSIC REMEDIATION TS
MICHIGAN AIR NATIONAL GUARD
W.K. KELLOGG MEMORIAL AIRPORT
BATTLE CREEK, MICHIGAN

Sample Location	Sample Number	Depth (fbgs)[a]
ESSB-1	ESSB1-26-26.5	26-26.5
ESSB-1	ESSB1-27.5-28	27.5-28
ESSB-2	ESSB2-2	2.0
ESSB-2	ESSB2-14	14.0
ESSB-2	ESSB-2-21.75-22.5	21.75-22.5
ESSB-3	ESSB3-2-2.5	2-2.5
ESSB-3	ESSB3-14-14.5	14-14.5
ESSB-3	ESSB3-22-22.5	22-22.5
ESSB-4	ESSB4-2-2.5	2-2.5
ESSB-4	ESSB4-14-14.5	14-14.5
ESSB-4	ESSB4-21.5-22	21.5-22
ESSB-5	ESSB5-2-2.5	2-2.5
ESSB-5	ESSB5-14-14.5	14-14.5
ESSB-5	ESSB5-21-21.5	21-21.5
ESSB-6[b]	ESSB6-2.75-3.5	2.75-3.5
ESSB-6[b]	ESSB6-4-4.5	4-4.5
ESSB-6[b]	ESSB6-13.5-14.25	13.5-14.25
ESSB-6[b]	ESSB6-21-21.5	21-21.5
ESSB-6[b]	ESSB6-27-27.5	27-27.5
ESSB-7	ESSB7-10-10.5	10-10.5
ESSB-8	ESSB8-10-10.5	10-10.5
ESSB-9	ESSB9-10-10.5	10-10.5
ESSB-10	ESSB10-5-5.5	5-5.5
ESSB-10	ESSB10-5-5.5	10-10.5

[a] fbgs = feet below ground surface.

[b] ESSB-6: this location is equivalent to ESMP-1

- Groundwater sampling, including

  - Water level measurements,

  - Visual inspection of water,

  - Well casing or monitoring point evacuation, and

  - Sampling;

- Sample preservation and transport, including

  - Sample preparation,

  - Onsite measurement of physical and geochemical parameters,

  - Sample labeling,

  - Transport of samples to the onsite USEPA mobile laboratory;

- Completion of sampling records; and

- Sample disposal.

Detailed groundwater sampling and sample handling procedures that were used are presented in the following sections.

2.2.1 Groundwater Sampling Locations

Groundwater samples were collected from previously installed monitoring wells and from newly installed groundwater monitoring points.

2.2.1.1 Monitoring Well Sampling Locations

Groundwater samples were collected from six monitoring wells. The wells that were sampled include MW-1 through MW-6. These wells were sampled using a peristaltic pump with dedicated polyethylene tubing. Locations of these wells are indicated on Figure 2.2.

2.2.1.2 Monitoring Point Locations

Groundwater samples were collected from 25 monitoring points at 13 locations. After completion of installation and development activities, monitoring points were sampled using a peristaltic pump and dedicated tubing. Locations of groundwater monitoring points are indicated on Figure 2.2.

2.2.2 Preparation for Sampling

All equipment used for sampling was assembled and properly cleaned and calibrated (if required) prior to arriving in the field. In addition, all record-keeping materials were gathered prior to leaving the office.

2.2.2.1 Equipment Cleaning

All portions of sampling and test equipment that contacted the samples were thoroughly cleaned before use. This equipment included the water level probe and cable, lifting line, test equipment for onsite use, and other equipment that contacted the samples or was placed downhole. The following cleaning protocol was used:

- Cleaned with potable water and phosphate-free laboratory detergent;
- Rinsed with potable water;
- Rinsed with distilled or deionized water;
- Rinsed with isopropyl alcohol;
- Air dried prior to use.

Any deviations from these procedures were documented in the field scientist's field notebook and on the groundwater sampling form.

2.2.2.2 Equipment Calibration

As required, field analytical equipment was calibrated according to the manufacturer's specifications prior to field use. This applied to equipment used for onsite measurements of DO, redox potential, pH, specific conductivity, and temperature.

2.2.3 Sampling Procedures

Special care was taken to prevent contamination of the groundwater and extracted samples through cross contamination from improperly cleaned equipment. Water level probes and cable used to determine static water levels and total depths of wells were thoroughly cleaned before and after field use and between uses at different sampling locations, using the procedures presented in Section 2.2.2.1. In addition, a clean pair of new, disposable nitrile gloves was worn by sampling personnel each time a different well was sampled.

2.2.3.1 Groundwater Monitoring Well and Monitoring Point Sampling

2.2.3.1.1 Preparation of Location

Prior to starting the sampling procedure, the area around the existing wells and new monitoring points was cleared of foreign materials, such as brush, rocks, and debris. This prevented sampling equipment from inadvertently contacting debris around the monitoring well/point.

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2.2.3.1.2 Water Level and Total Depth Measurements

Prior to removing any water from the monitoring well or monitoring point, the static water level was measured. An electric water level probe was used to measure the depth to groundwater to the nearest 0.01 foot below the datum. After measuring the static water level, the water level probe was slowly lowered to the bottom of the monitoring well/point, and the total depth was measured to the nearest 0.01 foot. Based on these measurements, the volume of water to be purged from the monitoring well/point was calculated.

2.2.3.1.3 Monitoring Well/Point Purging

The volume of water contained within the monitoring well/point casing at the time of sampling was calculated, and the wells/points were purged until at least three times the calculated volume was removed or until readings of DO, pH, and temperature had stabilized. All purge water was placed in USACE-provided, 55-gallon drums and disposed of by the USACE at designated industrial waste drains at the Base. A peristaltic pump was used for monitoring well and monitoring point purging.

2.2.3.1.4 Sample Extraction

Dedicated high-density polyethylene (HDPE) tubing and a peristaltic pump were used to extract groundwater samples from the monitoring wells and points. Where possible, the tubing was lowered through the casing into the water gently to prevent splashing. The sample was transferred directly into the appropriate sample container(s), with water carefully poured down the inner walls of the sample bottle to minimize aeration of the sample. Containers for samples to be analyzed for BTEX were filled to ensure that no headspace remained.

2.2.4 Onsite Chemical Parameter Measurement

2.2.4.1 Dissolved Oxygen Measurements

DO measurements were taken using an Orion® model 840 DO meter. To minimize aeration of the sample, DO concentration measurements were taken from a flow-through cell. The flow-through cell consisted of the DO probe and an Erlenmeyer flask into which groundwater extracted by a peristaltic pump was introduced and allowed to circulate. DO concentrations were recorded after the readings stabilized, and in all cases represent the lowest DO concentration observed.

2.2.4.2 Reduction/Oxidation Potential Measurements

Redox potential measurements were taken using an Orion® model 290A redox potential meter. Redox potential measurements were recorded after the readings stabilized and generally represent the lowest redox potential observed.

2.2.4.3 pH, Temperature, and Specific Conductivity

Because the pH, temperature, and specific conductivity of the groundwater change significantly within a short time following sample acquisition, these parameters were measured in the field or in the USEPA Mobile Laboratory immediately after collection. The measurements were made in a clean glass container separate from those intended for laboratory analysis, and the measured values were recorded on the groundwater sampling record or in the laboratory notebook.

2.2.5 Sample Handling

2.2.5.1 Sample Preservation

The USEPA mobile laboratory added any necessary chemical preservatives to sample containers prior to sampling.

2.2.5.2 Sample Container and Labels

Sample containers and appropriate container lids were provided by the onsite USEPA mobile laboratory. The sample containers were filled as described in Section 2.2.3.1.4, and the container lids were tightly closed. The sample label was firmly attached to the container side, and the following information was legibly and indelibly written on the label:

- Facility name;

- Sample identification;

- Sample type (groundwater);

- Sampling date;

- Sampling time;

- Preservatives added; and,

- Sample collector's initials.

2.2.5.3 Sample Shipment

After the samples were sealed and labeled, they were packaged for transport to the onsite USEPA mobile laboratory. The following packaging and labeling procedures were followed:

- Sample was packaged to prevent leakage or vaporization from its container;

- Shipping container was labeled with

   - Sample collector's name, address, and telephone number;

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- Laboratory's name, address, and telephone number;

- Description of sample;

- Quantity of sample; and

- Date of shipment.

The packaged samples were hand-delivered directly to the USEPA mobile laboratory. Delivery occurred shortly after sample acquisition. Samples for laboratory analysis at RSKERL in Ada, Oklahoma were maintained at a temperature of 4°C and packaged and shipped by RSKERL field personnel.

2.3 AQUIFER TESTING

2.3.1 Slug Testing

Aquifer slug tests were conducted to estimate the hydraulic conductivity of the shallow saturated zone at Site 3. Slug tests are single-well hydraulic tests used to determine the hydraulic conductivity of an aquifer in the immediate vicinity of the tested well. Slug tests can be used for both confined and unconfined aquifers that have a transmissivity of less than 7,000 square feet per day (ft^2/day). Slug testing can be performed using either a rising head or a falling head test. Rising head tests, which generally give more accurate results, were used at this site. Slug tests were performed in monitoring wells BC3-MW1, -2, -3, -5, and -6 (Figure 2.2). Detailed slug testing procedures are presented in the *Draft Technical Protocol for Implementing the Intrinsic Remediation with Long-Term Monitoring Option for Natural Attenuation of Dissolved-Phase Fuel Contamination in Groundwater* (Wiedemeier *et al.*, 1994), hereafter referred to as the Technical Protocol document.

2.3.2 Slug Test Data Analysis

Data obtained during slug testing were analyzed using AQTESOLV software (Geraghty and Miller, 1991) and the methods of Bouwer and Rice (1976) and Bouwer (1989) for unconfined conditions. The results of slug testing are presented in Section 3.3.

SECTION 3

PHYSICAL CHARACTERISTICS OF THE STUDY AREA

This section incorporates data collected during investigations summarized by ES (1993) and the more recent investigation conducted in August 1994, by Parsons ES in conjunction with researchers from the USEPA RSKERL. The investigative techniques used by Parsons ES and RSKERL researchers to determine the physical characteristics of the Fire Training Area, Site 3, are discussed in Section 2.

3.1 TOPOGRAPHY AND SURFACE WATER HYDROLOGY

The Base is located within the Central Lowland Province of the Interior Plains, a region characterized by slight local relief, and relatively low altitudes of 500 to 2,000 feet msl. The Base itself has gently rolling to nearly flat topography, with a large amount of paved area. The mean elevation of the airport is 941 feet msl (ES, 1993). At Site 3, the ground elevation is 920 to 910 feet msl, while west of the site, elevation varies from 890 to 920 feet msl. A topographic map of the Battle Creek, Michigan, region is presented in Figure 3.1. Some wet/swampy areas are present approximately 1,200 feet west of Site 3.

Major surface water features in the area include the Kalamazoo River, Harts Lake, and Gougac Lake. The Kalamazoo River is located approximately 1.5 miles north of the Base. Most streams in the area discharge into the Kalamazoo River. Gougac Lake is approximately 2 miles southeast of the Base, and Harts Lake is approximately 0.5 mile west of the Base.

Surface flow and runoff on the Base collect in low areas or infiltrate into the soil, eventually leaving the Base as groundwater or surface flow. Groundwater and small streams on the Base eventually discharge into the Kalamazoo River. Runoff from the western portion of the Base flows into wetlands, which feed into small streams that flow north to the Kalamazoo River.

3.2 REGIONAL GEOLOGY AND HYDROGEOLOGY

The Base lies upon Pleistocene-aged glacial drift that is estimated to be 110 to 135 feet thick (ES, 1993). The glacial deposits are outwash, which is material deposited by glacial melt water. The outwash deposits are typically heterogeneous and consist of sand, gravel, and some clayey intervals. Sand deposits range from fine- to very coarse-grained, but fine- to medium-grained deposits are more common. Sand layers are generally 10 to 15 feet thick. Sand and gravel units interbedded with the sand layers may be up to 20 feet thick. Clayey intervals are thinner and are more likely to be present in deeper sections of the outwash. Fragments of local bedrock are also common in the deeper sections.

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LEGEND

- - - - Base Boundary

CONTOUR INTERVAL 10 FEET

0   1/2   1 Mile

Bedrock beneath the glacial deposits is the Mississippian-aged Marshall Formation, which is 10 to 140 feet thick in the Battle Creek area. The Marshall Formation is a very fine- to coarse-grained sandstone containing layers of siltstone, shale, and sandy shale. The sandstones may be either hard or soft, depending upon cementing and/or weathering. Where cemented or hard, the Marshall Formation sandstones are fractured. Figure 3.2 shows the typical lithologic column in the Battle Creek area. Beneath the Marshall Formation is the Coldwater Shale, which may be up to 1,300 feet thick, consisting of thin layers of sandstone, limestone, and shale (Vanlier, 1966).

Groundwater is present in both the glacial deposits and the Marshall Formation. The glacial deposits act as an unconfined aquifer, while the Marshall Formation is a confined to semiconfined aquifer. The glacial deposits and the Marshall Formation are considered to be a single hydrologic unit, although clay layers may locally retard water movement between the two. Most water that enters the glacial unit eventually moves into the Marshall Formation and is discharged as stream flow or withdrawn through wells (Vanlier, 1966). The Marshall Formation is the major water supply source in the area, tapped by domestic, industrial, and municipal wells, although domestic wells are often completed in the glacial deposits.

The depth to groundwater varies with topography, but at the Base it generally is 10 to 40 feet below ground surface (bgs). The glacial deposits are recharged directly by precipitation and infiltration from the surface. The groundwater flow pattern in the glacial deposits typically mirrors topography. At the Base, groundwater flow is generally to the northwest. The horizontal hydraulic conductivities of the glacial deposits range from 15 to 110 feet per day (ft/day) (1.0×10^{-2} to 7.6×10^{-2} ft/min) (Vanlier, 1966).

The Marshall Formation yields water from two main units, termed the "upper sandstone" and the "lower sandstone" (Figure 3.2). The hydraulic conductivity of the Marshall Formation ranges from 150 ft/day (0.1 ft/min) in the upper unit to 550 ft/day (0.4 ft/min) in the lower unit (Vanlier, 1966). Recharge to these units comes from the overlying glacial deposits, and the direction of flow in the sandstone units is similar to that observed in the overlying units (Vanlier, 1966).

3.3 SITE GEOLOGY AND HYDROGEOLOGY

3.3.1 Lithology and Stratigraphic Relationships

Lithology and stratigraphic relationships in the shallow subsurface at Site 3 were initially characterized during the SI conducted by ES (1993). Five soil boreholes and six monitoring wells were installed in the immediate vicinity of Site 3. To further define hydrogeologic conditions and the extent of soil and groundwater contamination, Parsons ES installed 25 monitoring points at 13 CPT locations and collected 24 soil samples from 10 CPT sites in August 1994. Locations of the boreholes, wells, and monitoring points, are shown on Figures 2.2 and 3.3.

.Subsurface soil observed at the site consisted of fine to coarse sands and silty sands interlayered with gravel and cobbles. Downgradient of the site, in the boreholes for

3-3

Geologic unit			Lithologic characteristics	Hydrologic unit

Geologic unit — **Lithologic characteristics** — **Hydrologic unit**

Glacial deposits — Sand and gravel — Sand and gravel aquifer

—Bedrock surface—

Marshall Formation

Upper sandstone:
- Sandstone, very fine to medium
- Sandstone, very fine to fine, silty
- Sandstone, very fine to medium, some zones of very fine to fine sandstone and siltstone
- Sandstone, very fine to fine; some thin zones of siltstone and shale

Hydrologic: Upper sandstone aquifer

Upper siltstone — Siltstone — Confining bed

Lower sandstone:
- Sandstone, very fine to fine, shaly
- Sandstone, very fine to fine
- Sandstone, very fine to fine, silty; or sandy shale
- Sandstone, very fine to fine
- Sandstone, very fine to fine; silty; or sandy shale

"Openings" often reported

Hydrologic: Lower sandstone aquifer

Lower siltstone:
- Unit 1 — Siltstone
- Sandstone, very fine to fine, shaly or silty
- Unit 2 — Siltstone
- Sandstone, very fine to fine, shaly or silty

Shale:
- Shale A — Shale
- Sandstone, very fine to fine, shaly; or sandy shale
- Shale B — Shale
- Sandstone, very fine to fine, shaly

FIGURE 3.2

GENERALIZED REGIONAL LITHOLOGIC COLUMN

Site 3 (Fire Training Area)
Intrinsic Remediation TS
Michigan Air National Guard, W.K. Kellogg Airport
Battle Creek, Michigan

PARSONS ENGINEERING SCIENCE, INC.

Denver, Colorado
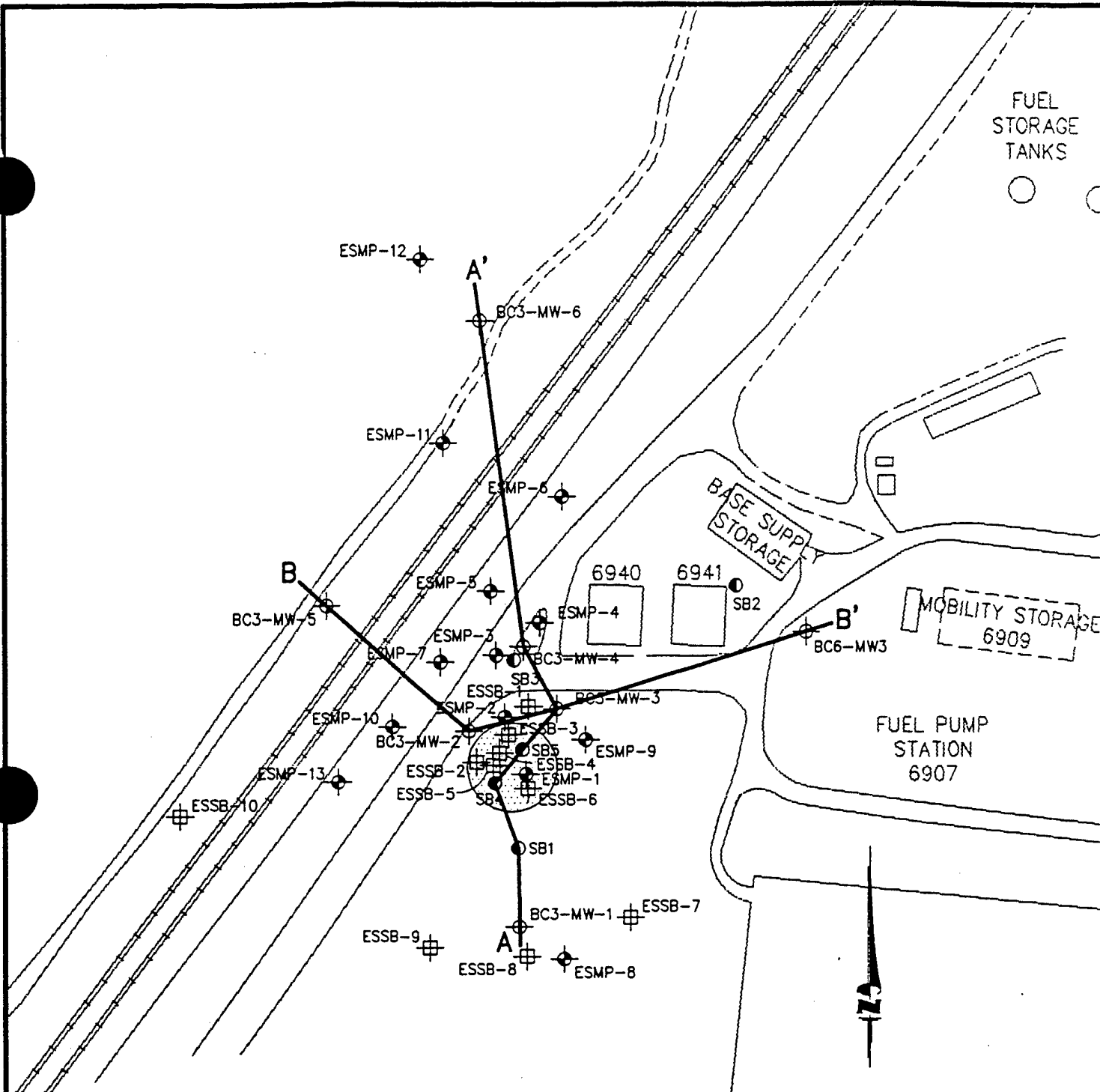
LEGEND

- ⊕ ESMP-1   MONITORING POINT (August 1994)
- ⊞ ESSB-1   SOIL BOREHOLE (August 1994)
- ⊕ BC3-MW-1   MONITORING WELL (1988-1989)
- ◗ SB1   SOIL BORING (1988-1989)
- ▨   FIRE TRAINING AREA
- A—A'   HYDROGEOLOGIC CROSS-SECTION

FIGURE 3.3

CROSS-SECTION LOCATION MAP

Site 3 (Fire Training Area)
Intrinsic Remediation TS
Michigan Air National Guard, W.K. Kellogg Airport
Battle Creek, Michigan

**PARSONS
ENGINEERING SCIENCE, INC.**

Denver, Colorado

monitoring wells BC3-MW5 and BC3-MW6, the deposits consisted of fine, loamy sand with some pebbles. The Marshall Formation was not encountered in the deepest boring, BC3-MW4, which was drilled to approximately 76 feet bgs (ES, 1993). Figure 3.3 shows the locations of cross-sections constructed based on logs of boreholes installed by ES in 1993. Figures 3.4 and 3.5 are hydrogeologic cross-sections which illustrate the type of subsurface conditions present in the vicinity of Site 3.

CPT operations in the vicinity of the fire training pit encountered layers of cobbles at approximately 9 and 23 feet bgs. The cobbles in these layers were large enough to repel the CPT apparatus. The depths of the cobble layers encountered by the CPT correspond to those indicated by previous soil boreholes installed at the Fire Training Area (ES, 1993). Sandy soil with gravel typically was above the cobble layers at the site. Sands near the groundwater surface often contained odorless black stringers (ESSB-1), thin clay stringers (ESSB-3), or gray sand with noticeable hydrocarbon odors (ESSB-6).

3.3.2 Groundwater Hydraulics

3.3.2.1 Flow Direction and Gradient

Groundwater at Site 3 occurs at a depth of approximately 27 feet bgs (Table 3.1). As indicated on Figure 3.3, groundwater flow in the Site 3 vicinity is generally toward the northwest. On the basis of available hydrogeologic data, this shallow aquifer is unconfined. August 1994 groundwater level data (Table 3.1) indicate the horizontal gradient was estimated to be approximately 0.003 foot per foot (ft/ft) to the northwest. Localized flow immediately west of the site appear to be more to the west with a gradient up to 0.007 ft/ft. As indicated on Figure 3.3, the overall groundwater flow direction is toward undeveloped land in the western and northwestern part of the Base. The Kalamazoo river, approximately 1.5 miles north of the site (Figure 3.1), is anticipated as the ultimate point of discharge for the shallow aquifer.

Downward vertical gradients ranging from 0.001 to 0.021 ft/ft were measured in monitoring points ESMP-1 through ESMP-6, which are in the vicinity of, or directly down-gradient from, the fire training pit (Figure 3.6). Upward vertical gradients ranging from -0.001 to -0.012 ft/ft were measured in areas west and northwest of the fire training pit. In typical groundwater flow systems, the vertical component of flow is downward in the vicinity of a divergent groundwater divide. However, no groundwater divide has been documented at the site. The vertical gradients are considered relatively slight and are attributed to heterogeneities in the soil stratigraphy that result in variable hydraulic conductivity, which cause local variations in the groundwater flow patterns.

3.3.2.2 Hydraulic Conductivity

Rising-head slug tests were conducted in five of the monitoring wells, by Parsons ES in August 1994 using methods described in Section 2.3. Results of these tests suggest that the hydraulic conductivity of the shallow portion of the aquifer ranges from 6.0×10^{-3} to 2.0×10^{-2} ft/min. Results of previous slug tests performed by ES (1993) gave hydraulic conductivity estimates ranging from 18 to 60 feet/day (1.3×10^{-2} to 4.2×10^{-2} ft/min.). Slug test data are presented in Table 3.2. Based on both historic and recent data, an average K for the area is estimated to be 1.14×10^{-2} ft/min.

FIGURE 3.4

HYDROGEOLOGIC CROSS SECTION A-A'

Site 3 (Fire Training Area)
Intrinsic Remediation TS
Michigan Air National Guard, W.K. Kellogg Airport
Battle Creek, Michigan

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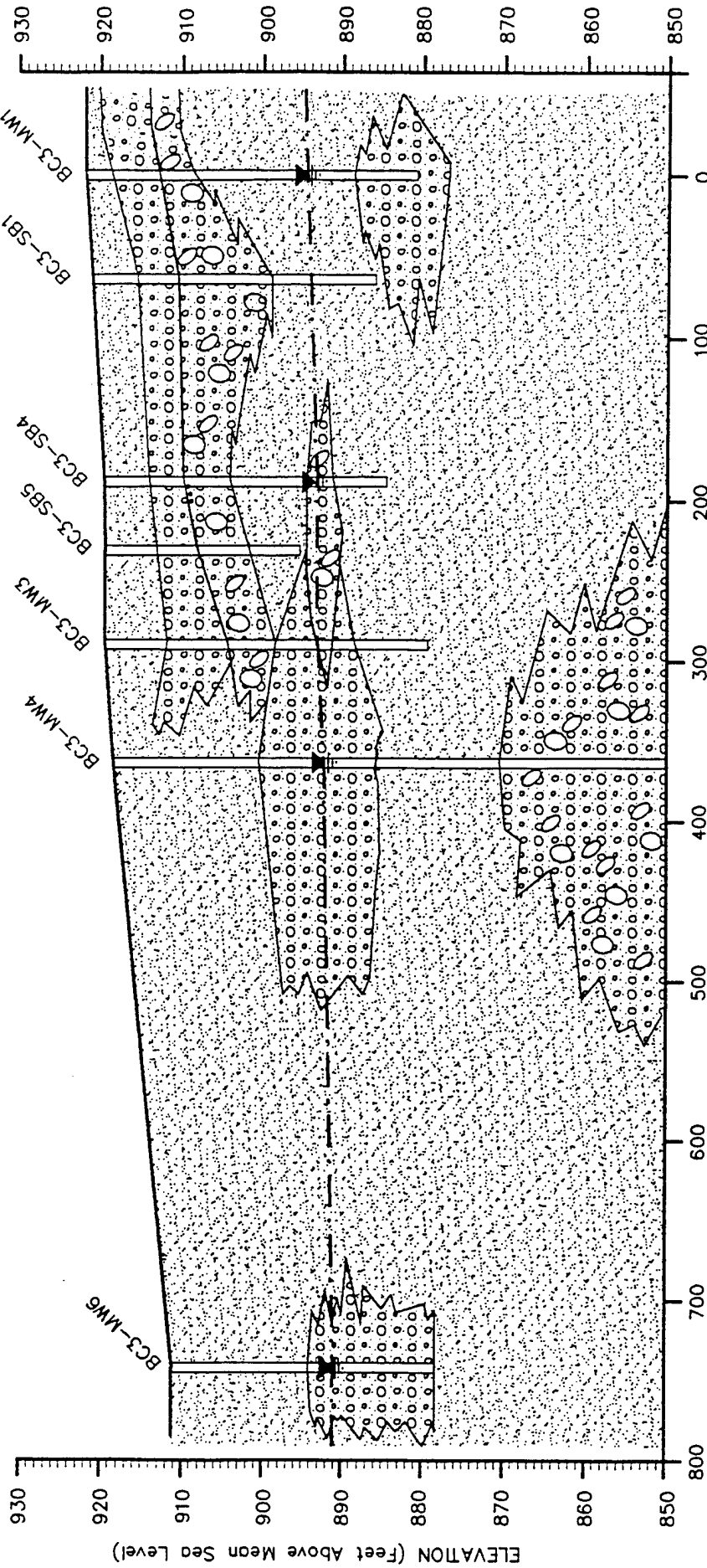
LEGEND

WELL IDENTIFICTION

MONITORING WELL AND
SOIL BORING LOCATION

LOCATION OF WATER TABLE

GEOLOGIC CONTACT
(DASHED WHERE INFERRED)

GRAVELLY SAND
WITH COBBLES

GRAVELLY SAND

SAND

VERTICAL EXAGGERATION 5x

0   50   100
FEET

ELEVATION (Feet Above Mean Sea Level)

FIGURE 3.5

HYDROGEOLOGIC
CROSS SECTION B-B'

Site 3 (Fire Training Area)
Intrinsic Remediation TS
Michigan Air National Guard, W.K. Kellogg Airport
Battle Creek, Michigan

PARSONS
ENGINEERING SCIENCE, INC.

Denver, Colorado

VERTICAL EXAGGERATION 5x

LEGEND

GRAVELLY SAND
WITH COBBLES

GRAVELLY SAND

SAND

SAND AND LOAM

BC3-MW5   WELL IDENTIFICATION

MONITORING WELL

LOCATION OF WATER TABLE

POINT OF GEOLOGIC CONTACT
(INFERRED)

ELEVATION (Feet Above Mean Sea Level)

FUEL STORAGE TANKS

890.0

ESMP-12

BC3-MW-6

890.5

ESMP-11

ESMP-6

BASE SUPPLY STORAGE

891.0

MOBILITY STORAGE 6909

ESMP-5

6940   6941   SB2

BC3-MW-5

ESMP-4

BC6-MW3

ESMP-7   ESMP-3   BC3-MW-4

SB3

ESMP-2   BC3-MW-3

ESMP-10   ESSB-3

BC3-MW-2   SB5   ESMP-9

891.5 FUEL PUMP STATION 6907

ESMP-13   ESSB-2   ESSB-4

ESSB-5   ESMP-1

SB4   ESSB-6

ESSB-10

SB1

892.0

ESSB-7

BC3-MW-1

ESSB-9

892.5

ESSB-8   ESMP-8

N

150 0 75   0   150

FEET

ESMP-1   MONITORING POINT

MW-1   MONITORING WELL

VW-1   BIOVENTING VENT WELL

DIRECTION OF GROUND WATER FLOW

892.5 ——— LINE OF EQUAL GROUND WATER ELEVATION (in feet MSL) (dashed where inferred)

FIRE TRAINING AREA
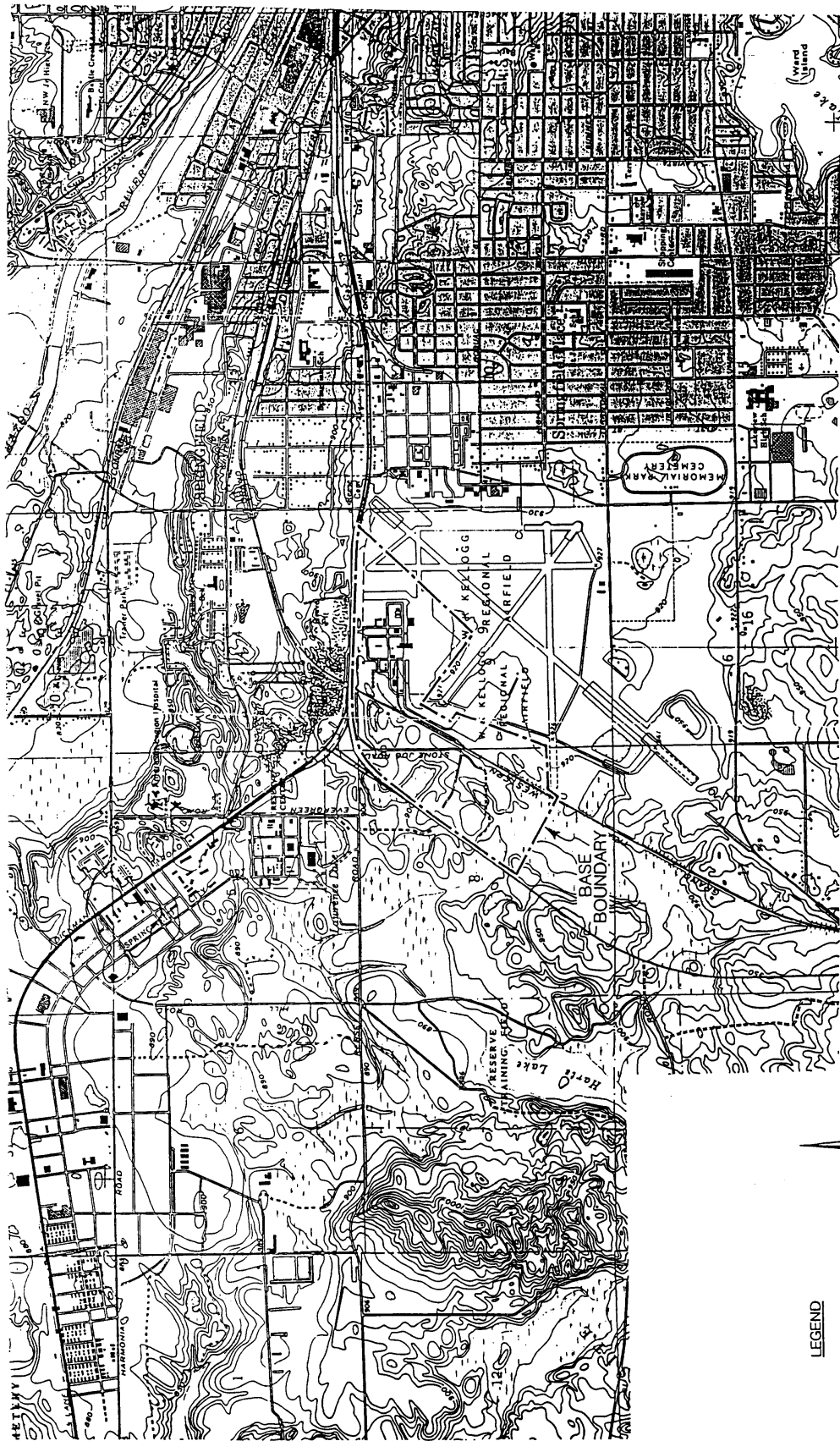
CONTOUR INTERVAL = 0.5 FOOT

FIGURE 3.6

GROUNDWATER SURFACE ELEVATION AUGUST 1994

Site 3 (Fire Training Area) Intrinsic Remediation TS Michigan Air National Guard, W.K. Kellogg Airport Battle Creek, Michigan

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TABLE 3.1
GROUND WATER ELEVATION DATA
SITE 3 (FIRE TRAINING AREA) INTRINSIC REMEDIATION TS
MICHIGAN AIR NATIONAL GUARD
W.K. KELLOGG MEMORIAL AIRPORT
BATTLE CREEK, MICHIGAN

Location	Datum Elevation[a] (ft msl) [b]	Ground Elevation[a] (ft msl)	Depth to Water (ft btoc) [c]	Ground Water Elev. (ft msl) (8/23/94)
ESMP-1S	919.10	NA[d]	26.99	892.11
ESMP-1D	919.09	NA	26.93	892.16
ESMP-2S	918.54	NA	26.56	891.98
ESMP-2D	918.48	NA	26.51	891.97
ESMP-3S	918.20	NA	26.51	891.69
ESMP-3D	918.24	NA	26.61	891.63
ESMP-3DD	918.14	NA	26.78	891.36
ESMP-4S	916.95	917.21	25.5	891.45
ESMP-4D	916.83	NA	25.66	891.17
ESMP-5S	916.38	NA	25.11	891.27
ESMP-5D	916.39	NA	25.23	891.16
ESMP-6S	915.39	915.65	24.62	890.77
ESMP-6D	915.31	NA	24.67	890.64
ESMP-7S	917.10	917.43	25.53	891.57
ESMP-7D	917.18	NA	25.57	891.61
ESMP-8S	921.11	NA	28.43	892.68
ESMP-8D	920.98	NA	28.54	892.44
ESMP-9S	918.95	NA	26.91	892.04
ESMP-10S	917.66	917.96	25.85	891.81
ESMP-10D	917.67	NA	25.85	891.82
ESMP-11S	911.20	908.15	20.88	890.32
ESMP-11D	911.18	NA	20.85	890.33
ESMP-12S	914.32	911.97	25.14	889.18
ESMP-12D	914.47	NA	25.06	889.41
ESMP-13S	918.72	918.11	NA	891.56
BC3-MW1	923.16	921.90	30.36	892.80
BC3-MW2	920.73	919.70	28.54	892.19
BC3-MW3	920.30	919.40	28.08	892.22
BC3-MW4	920.42	918.60	28.80	891.62
BC3-MW5	920.28	918.74	30.03	890.25
BC3-MW6	913.42	911.92	23.32	890.10

[a] Datum elevation and ground elevation are referenced to BC3-MW3
which has a known ground elevation of 919.4 ft msl.

[b] ft msl = feet above mean sea level.

[c] ft btoc = feet below top of casing.

[d] NA = data not available.

TABLE 3.2
SLUG TEST RESULTS
SITE 3 (FIRE TRAINING AREA) INTRINSIC REMEDIATION TS
MICHIGAN AIR NATIONAL GUARD
W.K. KELLOGG MEMORIAL AIRPORT
BATTLE CREEK, MICHIGAN

WELL	DATE*	TEST	HYDRAULIC CONDUCTIVITY (feet/minute)	HYDRAULIC CONDUCTIVITY (ft/sec)
BC3-MW1	8/23/94	Rising Head #1	1.01×10^{-2}	1.68×10^{-4}
BC3-MW2	8/23/94	Rising Head #1	1.36×10^{-2}	2.27×10^{-4}
	1/12/89	Rising Head #1	4.03×10^{-2}	6.72×10^{-4}
BC3-MW3	8/23/94	Rising Head #1	1.00×10^{-2}	1.67×10^{-4}
BC3-MW3	8/23/94	Rising Head #2	2.00×10^{-2}	3.33×10^{-4}
	1/12/89	Rising Head #1	1.54×10^{-2}	2.57×10^{-4}
BC3-MW5	8/23/94	Rising Head #2	1.26×10^{-2}	2.1×10^{-4}
BC3-MW5	8/23/94	Rising Head #3	9.97×10^{-3}	1.66×10^{-4}
BC3-MW6	8/23/94	Rising Head #1	6.00×10^{-3}	1.00×10^{-4}
BC3-MW6	8/23/94	Rising Head #2	7.00×10^{-3}	1.17×10^{-4}
		AVERAGE	1.14×10^{-2}	1.9×10^{-4}

* Slug tests performed 8/23/94 by Parsons ES as part of this TS. Slug tests performed 1/12/89 as part of previous site investigation (ES, 1993).

3.3.2.3 Effective Porosity

Because of the difficulty involved in accurately determining effective porosity, accepted literature values for the type of soil comprising the shallow saturated zone were used. Freeze and Cherry (1979) give a range of effective porosity for sand and/or gravel of 0.25 to 0.50. To be conservative (lower effective porosity results in greater groundwater velocity), the effective porosity for sediments of the shallow saturated zone is assumed to be 0.25.

3.3.2.4 Advective Groundwater Velocity

The advective velocity of ground water in the direction parallel to ground water flow is given by:

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$$\bar{v} = \frac{-K}{n_e} \frac{dH}{dL}$$

Where: $\bar{v}$ = Average advective ground water velocity (seepage velocity) [L/T]

K = Hydraulic conductivity [L/T]

dH/dL = Gradient [L/L]

n_e = Effective porosity.

Using this relationship in conjunction with the site-specific groundwater gradient (0.003 ft/ft) and hydraulic conductivity (0.0114 ft/min) data, the average advective groundwater velocity at the site can be calculated. To define a range of advective groundwater velocities based on the range of porosities values indicated by Freeze and Cherry (1979), calculations were made for porosities of 0.25 and 0.50. Using an effective porosity of 0.25, the average advective groundwater velocity at the site is 0.197 ft/day, or approximately 72 feet per year (ft/yr). An effective porosity of 0.50 yields an average velocity of 0.098 ft/day (36 ft/yr).

3.3.2.5 Preferential Flow Paths

No obvious preferential flow paths have been identified at the site. Groundwater occurs approximately 27 ft bgs, substantially beneath surface discharge points and subsurface utility corridors. A sewer line runs parallel to the north-south road adjacent to the fire training pit. However, because groundwater is at least 20 feet below this line, it is not a potential groundwater migration conduit. Streams or ponds that could mobilize contamination are not currently present at the site. Precipitation at the site collects in low areas or infiltrates into the soil to recharge the shallow aquifer. Groundwater eventually discharges into the Kalamazoo River to the north of the site.

3.3.3 Groundwater Use

Primary potable water supplies, including those for the Base and the airport, are obtained from the Battle Creek municipal water system, although some domestic supply wells are present north of the Base. These domestic wells are screened in the glacial material, and organic contaminants were detected in these wells in 1987 (ES, 1993). In addition, sampling of wells at the Base perimeter detected low concentrations of volatile organic compounds (VOCs). However, given the available evidence, it appears unlikely that contamination from Site 3 is responsible for the offsite detections.

3.4 CLIMATOLOGICAL CHARACTERISTICS

The climate of the Battle Creek area varies between continental and semimaritime. Prevailing winds from the Great Lakes often alter the typical continental-type climate to a more moderate semimaritime climate. Precipitation is fairly uniform throughout the year. The average annual precipitation for the period from 1982 to 1986 was 39.6 inches, with May and July typically being the wettest months (US Department of Commerce, 1982 - 1986).

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SECTION 4

NATURE AND EXTENT OF SOIL AND GROUNDWATER
CONTAMINATION

4.1 SOURCE OF CONTAMINATION

Fire training exercises were conducted at this site from about 1977 through 1986. Waste mixtures were floated on top of water in the fire training pit, ignited for training exercises, and then extinguished. Wastes included a total volume of approximately 54,000 to 74,000 gallons of mixtures of waste JP-4, waste oils, waste hydraulic fluid, and spent cleaning solvents. Drums of waste were stored in an area north of the fire training pit prior to use in fire training exercises.

4.2 SOIL CHEMISTRY

4.2.1 Residual Contamination

Residual light nonaqueous phase liquid (LNAPL) is defined as the LNAPL that is trapped in the aquifer by the processes of cohesion and capillarity and therefore will not flow within the vadose zone and will not flow from the aquifer matrix into a well under the influence of gravity. Mobile LNAPL is defined as the LNAPL that is free to flow into the aquifer and that will flow from the aquifer matrix into a well under the influence of gravity. Mobile LNAPL has not been detected in monitoring wells or monitoring points at Site 3. However, observations made during installation of a bioventing unit in the center of the fire training pit documented shallow soils apparently saturated with fuel hydrocarbons (ES, 1992). These conditions are believed to extend throughout the entire vadose zone at the site. The following sections describe the residual contamination found at Site 3.

4.2.1.1 Soil BTEX Contamination

Soil samples collected in 1994 were analyzed for BTEX compounds using modified RSKERL method RSKSOP-124. Residual BTEX contamination resulting from vertical and lateral migration of contaminants applied at the surface was detected in samples from only two CPT boreholes. Both of these were located within the bermed area of the fire training pit, which is the presumed source area. Laboratory analytical results are summarized in Table 4.1 Figure 4.1 shows the location of the soil boreholes with confirmed BTEX contamination and the associated concentrations detected.

The highest observed total BTEX concentration was 4.98 milligrams per kilogram (mg/kg) in a soil sample collected from 27 to 27.5 feet bgs at ESSB-6. This sample was

LEGEND

⊕ ESMP-1   MONITORING POINT

⊞ ESSB-1   SOIL BOREHOLE

⊕ MW-1   MONITORING WELL

▨   FIRE TRAINING AREA

ESSB-1		
B	14-14.5/0.0154	DEPTH OF SAMPLE (feet bgs)/TOTAL BTEX (mg/kg)
T	2-2.5/2900	DEPTH OF SAMPLE (feet bgs)/TPH (mg/kg)

FUEL STORAGE TANKS

BASE SUPPLY STORAGE

MOBILITY STORAGE 6909

FUEL PUMP STATION 6907

6940 6941

ESSB-1	
B	ND
T	26-26.5/60

ESSB-4	
B	ND
T	2-2.5/4700
	14-14.5/1020
	21.5-22/600

ESSB-6	
	4-4.5/0.1091
	21-21.5/0.0163
B	27-27.5/4.9825
	2.75-3.5/48500
	4-4.5/5310
T	13.5-14/390
	21-21.5/ND
	27-27.5/2460

ESSB-2	
B	ND
T	2-2.5/9910
	14-14.5/6490

ESSB-5	
B	14-14.5/0.0154
T	2-2.5/2900
	14-14.5/22810

FEET
150 0 75   0   150

FIGURE 4.1

MEASURED SOIL BTEX
AND TPH
AUGUST 1994

Site 3 (Fire Training Area)
Intrinsic Remediation TS
Michigan Air National Guard, W.K. Kellogg Airport
Battle Creek, Michigan

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TABLE 4.1

FUEL HYDROCARBONS AND CHLORINATED VOCs DETECTED IN SOIL
SITE 3 (FIRE TRAINING AREA) INTRINSIC REMEDIATION TS
MICHIGAN AIR NATIONAL GUARD
W.K. KELLOGG MEMORIAL AIRPORT
BATTLE CREEK, MICHIGAN

Sample Location	Depth (fbgs)[a]	Benzene (mg/kg)	Toluene (mg/kg)	Ethylbenzene (mg/kg)	p-Xylene (mg/kg)	m-Xylene (mg/kg)	o-Xylene (mg/kg)	Total Xylenes (mg/kg)	Total BTEX (mg/kg)	TPH (mg/kg)
ESSB-1	26-26.5	BLQ[b]	BLQ	ND[c]	ND	ND	ND	ND	BLQ	60
ESSB-1	27.5-28	ND	BLQ	ND	ND	ND	ND	ND	BLQ	<60
ESSB-2	2-2.5	BLQ	BLQ	ND	BLQ	ND	BLQ	BLQ	BLQ	9910
ESSB-2	14	ND	BLQ	ND	ND	ND	ND	ND	BLQ	6490
ESSB-2	21.75-22.5	ND	BLQ	ND	ND	ND	ND	ND	BLQ	<60
ESSB-3	2-2.5	ND	BLQ	ND	ND	ND	ND	ND	BLQ	<60
ESSB-3	2-2.5(D)[d]	ND	BLQ	ND	ND	ND	ND	ND	BLQ	NA
ESSB-3	14-14.5	ND	BLQ	ND	ND	ND	ND	ND	BLQ	<60
ESSB-3	22-22.5	ND	BLQ	ND	ND	ND	ND	ND	BLQ	<60
ESSB-4	2-2.5	ND	BLQ	ND	BLQ	ND	BLQ	BLQ	BLQ	4700
ESSB-4	14-14.5	ND	BLQ	ND	ND	ND	ND	ND	BLQ	1020
ESSB-4	21.5-22	ND	BLQ	ND	ND	ND	BLQ	BLQ	BLQ	600
ESSB-5	2-2.5	ND	BLQ	ND	ND	ND	ND	ND	BLQ	2900
ESSB-5	14-14.5	ND	0.0154	ND	BLQ	ND	BLQ	BLQ	0.0154	22810
ESSB-5	21-21.5	ND	BLQ	ND	ND	ND	ND	ND	BLQ	<60
ESSB-6	2.75-3.5	ND	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	48500
ESSB-6	4-4.5	0.0139	0.0156	BLQ	0.0222	0.043	0.0144	0.0796	0.1091	5310
ESSB-6	13.5-14.25	ND	BLQ	ND	ND	ND	ND	0	BLQ	390
ESSB-6	21-21.5	ND	BLQ	ND	BLQ	ND	0.0163	0.0163	0.0163	<60
ESSB-6	21-21.5(D)	BLQ	BLQ	BLQ	0.0316	0.0439	0.0922	0.1677	0.1677	NA
ESSB-6	27-27.5	0.0203	0.0307	0.731	1.69	2.48	0.0305	4.2005	4.9825	2460
ESSB-7	10-10.5	ND	BLQ	ND	ND	ND	ND	ND	BLQ	<60
ESSB-8	10-10.5	BLQ	BLQ	ND	ND	ND	BLQ	BLQ	BLQ	<60
ESSB-9	10-10.5	ND	BLQ	ND	ND	ND	ND	ND	BLQ	<60
ESSB-10	5-5.5	ND	BLQ	ND	ND	ND	ND	ND	BLQ	<60
ESSB-10	18.5-19	ND	BLQ	ND	ND	ND	ND	ND	BLQ	<60

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FUEL HYDROCARBONS AND CHLORINATED VOCs DETECTED IN SOIL
SITE 3 (FIRE TRAINING AREA) INTRINSIC REMEDIATION TS
MICHIGAN AIR NATIONAL GUARD
W.K. KELLOGG MEMORIAL AIRPORT
BATTLE CREEK, MICHIGAN

Sample Location	Depth (fbgs)[a]	1,3,5-TMB[e] (mg/kg)	1,2,4-TMB (mg/kg)	1,2,3-TMB (mg/kg)	NAPHT[f] (mg/kg)	2-MENAPH[g] (mg/kg)	1-MENAPH (mg/kg)	(EPA)[j] TCE[h] (µg/kg)	(EPA)[j] PCE[i] (µg/kg)	(EVG)[k] TCE[h] (µg/kg)	(EVG)[k] PCE[i] (µg/kg)
ESSB-1	26-26.5	ND	ND	ND	ND	BLQ	BLQ	28.8	1360	5.0	170.0
ESSB-1	27.5-28	ND	ND	ND	ND	BLQ	ND	ND	90.6	ND	1.9
ESSB-2	2-2.5	BLQ	BLQ	BLQ	ND	ND	ND	ND	35.3	ND	430.0
ESSB-2	14	BLQ	ND	BLQ	ND	ND	ND	ND	19.1	ND	6.9
ESSB-2	21.75-22.5	BLQ	BLQ	ND	ND	BLQ	ND	ND	62.1	ND	1.5
ESSB-3	2-2.5	ND	ND	ND	ND	ND	ND	ND	124	1.5	3.0
ESSB-3	2-2.5(D)	ND	ND	ND	ND	BLQ	ND	ND	133	NA	NA
ESSB-3	14-14.5	ND	ND	ND	ND	BLQ	ND	ND	60.4	ND	2.8
ESSB-3	22-22.5	ND	BLQ	ND	ND	BLQ	ND	ND	69.4	ND	2.6
ESSB-4	2-2.5	ND	BLQ	ND	ND	ND	ND	ND	93.4	ND	7800.0
ESSB-4	14-14.5	ND	ND	ND	ND	ND	ND	ND	21	ND	350.0
ESSB-4	21.5-22	BLQ	BLQ	ND	ND	BLQ	ND	ND	27.2	ND	980.0
ESSB-5	2-2.5	ND	ND	ND	ND	ND	ND	ND	24.3	ND	420.0
ESSB-5	14-14.5	ND	BLQ	BLQ	ND	ND	ND	ND	30.9	ND	260.0
ESSB-5	21-21.5	ND	BLQ	BLQ	ND	BLQ	BLQ	BLQ	BLQ	ND	60.0
ESSB-6	2.75-3.5	ND	BLQ	BLQ	ND	ND	ND	ND	21.6	ND	490.0
ESSB-6	4-4.5	BLQ	0.0135	BLQ	BLQ	BLQ	BLQ	BLQ	34	ND	99.0
ESSB-6	13.5-14.25	ND	ND	ND	ND	BLQ	ND	ND	22.9	ND	4.6
ESSB-6	21-21.5	0.0312	0.0242	0.0631	BLQ	0.0171	BLQ	ND	31	ND	6.0
ESSB-6	21-21.5(D)	0.299	0.286	0.391	0.0133	0.119	0.108	ND	22.6	NA	NA
ESSB-6	27-27.5	6.13	10.6	5.97	1.69	4.65	3.69	BLQ	25.6	ND	39.0
ESSB-7	10-10.5	ND	ND	ND	ND	BLQ	ND	ND	40.1	2.0	3.7
ESSB-8	10-10.5	ND	BLQ	ND	ND	BLQ	ND	ND	46.5	4.1	4.0
ESSB-9	10-10.5	ND	ND	ND	BLQ	BLQ	ND	ND	16	4.7	7.5
ESSB-10	5-5.5	ND	ND	ND	ND	BLQ	ND	ND	80.7	ND	23.0
ESSB-10	18.5-19	ND	ND	ND	ND	BLQ	ND	ND	32.2	ND	11.0

a/ fbgs = feet below ground surface.
b/ BLQ = Below limit of quantitation, or <0.02 mg/kg.
c/ ND = Not detected.
d/ (D) = Duplicate sample
e/ TMB = Trimethybenzene
f/ NAPHT = Naphthalene

g/ MENAPH = Methylnaphthalene
h/ TCE = Trichloroethylene
i/ PCE = Tetrachloroethylene
j/ EPA = RSKERL
k/ EVG = Evergreen Analytical Laboratories

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collected near the water table. Samples from 4 to 4.5 feet bgs and 21 to 21.5 feet bgs from the same borehole contained concentrations of BTEX an order of magnitude lower than observed in the deepest sample. A total BTEX concentration of 0.0154 mg/kg was reported from a sample collected at 14 to 14.5 feet bgs at ESSB-5. Benzene was detected in samples from ESSB-6 at 4 to 4.5 feet bgs and 27 to 27.5 feet bgs at concentrations of 0.0139 mg/kg and 0.0203 mg/kg, respectively.

In the previous SI study (ES, 1993), BTEX concentrations were estimated to be as high as 7,000 mg/kg. Chlorobenzene was reported at a concentration of 0.14 mg/kg in one sample, and lead was reported at a concentration of 725 mg/kg. Field observations during the SI phase of work indicated petroleum odors in soil samples near the water table. Soils collected from above the water table were described as having an oily appearance in several boreholes (ES, 1993).

Field work performed by ES in 1992 involved the installation of a bioventing unit in the center of the fire training pit to remediate contaminated soils. Soils characterized by a strong hydrocarbon odor and saturation with oil or fuel were encountered in the center of the pit. The vent well contained the highest soil gas and soil hydrocarbons concentrations encountered during installation of the bioventing system. Total volatile hydrocarbons (TVH) ranged from 88 parts per million, volume per volume (ppmv) at MPC-17 to 29,000 ppmv at the vent well. Total BTEX concentrations of 32.8 mg/kg and total recoverable petroleum hydrocarbons (TRPH) of 15,000 mg/kg were reported for soil samples collected during the installation of the vent well. Benzene was also detected in the soil gas samples from the vent well at a concentration of 120 ppmv (ES, 1992). BTEX compounds were not detected in samples collected at the vent well after operating the bioventing unit for one year. TVH was detected at the vent well at a concentration of 1.5 ppmv and TRPH was detected at a concentration of 3,140 mg/kg following the initial one-year test period (ES, unpublished data). These results indicate a significant reduction in both soil gas hydrocarbons and residual soil hydrocarbons due to bioventing operations.

4.2.1.2 Total Petroleum Hydrocarbons

Soil samples collected in 1994 were analyzed for total petroleum hydrocarbons (TPH) using method RSKSOP-174 calibrated with a JP-4 standard. TPH compounds were only detected in soil samples collected from boreholes within the fire training pit, with the exception of one sample downgradient of the pit (ESSB-1). The area where TPH were detected is indicated on Figure 4.1. Table 4.1 contains soil TPH data.

The highest concentrations of TPH were generally detected within the upper 3.5 feet of soil. The highest TPH level of 48,500 mg/kg was reported at ESSB-6 (2.8 to 3.5 feet bgs). ESSB-6 is east of the bioventing vent well, in the eastern half of the fire training pit (Figure 4.1). In general, TPH contamination appears to be confined within the bermed Fire Training Area, and concentrations tend to decrease with depth. However, samples from two locations indicated the presence of TPH near the water table. A sample from 27 to 27.7 feet bgs at ESSB-6 contained 2,460 mg/kg of TPH and a sample from ESSB-1 at 26 to 26.5 feet bgs contained 60 mg/kg of TPH. The lack of correlation between the distribution of TPH concentrations and BTEX concentrations may result from bioventing or natural weathering processes. Compared to heavier compounds in a fuel mixture,

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BTEX compounds are more volatile and soluble, less retarded, and more susceptible to natural biodegradation. As a result, the BTEX concentrations in soil would be expected to decrease more rapidly relative to other heavier constituents in a fuel mixture (i.e., more rapidly than TPH). The preferential removed of BTEX during bioventing is described in Section 5.6.2.

4.2.1.3 Chlorinated Volatile Organic Compounds

Soil samples collected in 1994 were analyzed for chlorinated VOCs by EPA RSKERL using RSKERL method RSKSOP-124 and by Evergreen Analytical, Inc., using method SW8010. Analytical results are presented in Table 4.1. Tetrachloroethylene (PCE) concentrations ranged from 1.5 µg/kg (ESSB-2 from 21.75 to 22.5 feet bgs) to 7,800 µg/kg (ESSB-4 from 2 to 2.5 feet bgs). Trichloroethylene (TCE) was detected in four soil samples at concentrations ranging from 1.5 µg/kg (ESSB-3 at 2 to 2.5 feet bgs) to 5.0 µg/kg (ESSB-1 at 26 to 26.5 feet bgs).

4.2.2 Total Organic Carbon

TOC concentrations are used to estimate the amount of organic matter sorbed onto soil particles or trapped in the interstitial passages of a soil matrix. The TOC concentration in the saturated zone is an important parameter used to estimate the amount of contaminant that could potentially be sorbed onto the aquifer matrix. Sorption results in retardation of the contaminant plume relative to the average adjective groundwater velocity. Measurements of TOC were taken from core samples obtained from several CPT locations. Values from samples that also contained concentrations of TPH above the TPH method detection limit of 60 mg/kg were disregarded. TOC concentrations in the uncontaminated soil at this site ranged from 0.029 to 0.098 percent (Table 4.2) Values exceeding these levels were detected in samples that also contained concentrations of TPH above 60 mg/kg. Background levels of TOC are considered as those measurements taken at locations ESSB-7 through ESSB-10, which are upgradient and cross-gradient of contamination and located in the upper 10 feet of the soil profile. The average TOC concentration for these background soil samples was 0.0585 percent.

4.3 Groundwater Chemistry

4.3.1 Dissolved Contamination

Laboratory analytical results for groundwater samples collected during the previous SI indicated the presence of petroleum hydrocarbon contamination in the shallow saturated zone in the vicinity of Site 3 (ES, 1993). Groundwater samples collected in August 1994 by Parsons ES and RSKERL personnel confirmed the presence of petroleum hydrocarbons. Table 4.3 summarizes available groundwater contaminant data.

4.3.1.1 BTEX in Groundwater

Groundwater samples collected in 1994 were analyzed for BTEX compounds using RSKERL method RSKSOP-148. Figure 4.2 is an isopleth map that shows the distribution of total BTEX dissolved in groundwater. Isopleths are drawn based on the maximum concentrations detected at the nested monitoring points or at monitoring wells.

TABLE 4.2
TOTAL ORGANIC CARBON (TOC) IN SOIL
SITE 3 (FIRE-TRAINING AREA) INTRINSIC REMEDIATION TS
MICHIGAN AIR NATIONAL GUARD
W.K. KELLOGG MEMORIAL AIRPORT
BATTLE CREEK, MICHIGAN

Sample Location	Depth (fbgs)[a]	% TOC (mean ± SD[b])
ESSB-1	26-26.5	7.27 ± 0.48[d]
ESSB-1	27.5-28	0.144 ± 0.006
ESSB-2	2.0	0.452 ± 0.016[d]
ESSB-2	14.0	0.148 ± 0.006[d]
ESSB-2	21.75-22.5	0.07 ± 0.018
ESSB-3	2-2.5	0.088 ± 0.016
ESSB-3	14-14.5	0.053 ± 0.006
ESSB-3	22-22.5	0.058 ± 0.004
ESSB-4	2-2.5	0.619 ± 0.103[d]
ESSB-4	14-14.5	0.143 ± 0.002[d]
ESSB-4	21.5-22	0.159 ± 0.027[d]
ESSB-5	2-2.5	0.526 ± 0.088[d]
ESSB-5	14-14.5	0.324 ± 0.028[d]
ESSB-5	21-21.5	0.044 ± 0.001
ESSB-6[c]	2.75-3.5	0.671 ± 0.001[d]
ESSB-6[c]	4-4.5	0.603 ± 0.139[d]
ESSB-6[c]	13.5-14.25	0.093 ± 0.013[d]
ESSB-6[c]	21-21.5	0.082 ± 0.003
ESSB-6[c]	27-27.5	0.087 ± 0.002[d]
ESSB-7	10-10.5	0.07 ± 0.018
ESSB-8	10-10.5	0.098 ± 0.036
ESSB-9	10-10.5	0.055 ± 0.001
ESSB-10	5-5.5	0.041 ± 0.002
ESSB-10	10-10.5	0.029 ± 0.004

[a] fbgs = feet below ground surface.

[b] SD = one standard deviation

[c] ESSB-6: this location is equivalent to ESMP-1

[d] considered as unrepresentative of background conditions due to detection of TPH > 60 mg/kg (see Table 4.1)

TABLE 4.3
FUEL HYDROCARBONS AND CHLORINATED VOCs DETECTED IN GROUND WATER
SITE 3 (FIRE TRAINING AREA) INTRINSIC REMEDIATION TS
MICHIGAN AIR NATIONAL GUARD
W.K. KELLOGG MEMORIAL AIRPORT
BATTLE CREEK, MICHIGAN

Sample Location	Sample Date	Benzene (µg/L)	Toluene (µg/L)	Ethylbenzene (µg/L)	m+p-Xylene (µg/L)	o-Xylene (µg/L)	Total Xylenes (µg/L)	Total BTEX (µg/L)	1,3,5-TMB[a] (µg/L)	1,2,4-TMB (µg/L)	1,2,3-TMB (µg/L)	c-1,2-DCE[b] (µg/L)	TCE[c] (µg/L)	PCE[d] (µg/L)
ESMP1S	8/19/94	25.90	4.30	123.00	863.00	100.00	963.00	1116.20	112.00	223.00	163.00	22.70	BLC[c]	1.50
ESMP1D	8/19/94	BLC	2.20	BLC	2.20	BLC	2.20	4.40	BLC	1.60	1.10	BLC	BLC	BLC
ESMP2S	8/19/94	BLC	BLC	2.60	4.60	BLC	4.60	7.20	BLC	3.70	4.70	1.00	BLC	BLC
ESMP2S(D)[e]	8/19/94	BLC	1.00	2.80	4.90	BLC	4.90	8.70	BLC	3.60	4.80	1.00	BLC	BLC
ESMP2D	8/19/94	BLC	BLC	2.90	20.10	3.10	23.20	26.10	3.10	7.10	4.80	BLC	BLC	BLC
ESMP3S	8/19/94	BLC	BLC	BLC	3.90	BLC	3.90	3.90	BLC	2.00	1.40	BLC	BLC	2.50
ESMP3D	8/19/94	BLC	BLC	1.70	12.90	2.20	15.10	16.80	2.30	5.40	3.90	BLC	BLC	BLC
ESMP3DD	8/20/94	BLC	BLC	BLC	BLC	BLC	BLC	BLC	BLC	1.50	1.20	BLC	BLC	BLC
ESMP4S	8/20/94	BLC	BLC	BLC	4.20	BLC	4.20	4.20	1.00	2.50	1.70	BLC	BLC	BLC
ESMP4D	8/20/94	BLC	BLC	BLC	1.10	BLC	1.10	1.10	BLC	1.30	1.00	BLC	2.30	BLC
ESMP5S	8/20/94	BLC	1.40	BLC	1.40	BLC	1.40	2.80	BLC	2.70	1.60	BLC	BLC	2.00
ESMP5D	8/20/94	BLC	BLC	BLC	1.90	BLC	1.90	1.90	BLC	1.50	1.00	1.60	BLC	BLC
ESMP5D(D)	8/20/94	BLC	BLC	BLC	2.00	BLC	2.00	2.00	BLC	1.40	1.10	1.50	BLC	BLC
ESMP6S	8/20/94	BLC	BLC	BLC	1.90	BLC	1.90	1.90	BLC	1.60	1.00	BLC	BLC	BLC
ESMP6D	8/20/94	BLC	BLC	BLC	BLC	BLC	BLC	BLC	BLC	1.00	BLC	BLC	BLC	BLC
ESMP7S	8/20/94	12.40	1.10	10.20	25.40	BLC	25.40	49.10	BLC	28.10	18.80	117.00	1.10	1.80
ESMP7S(D)	8/20/94	13.60	1.30	10.70	28.40	BLC	28.40	54.00	BLC	29.00	19.60	125.00	1.10	1.60
ESMP7D	8/20/94	4.20	BLC	5.10	2.10	BLC	2.10	11.40	BLC	1.80	BLC	29.20	BLC	BLC
ESMP8S	8/20/94	BLC	BLC	BLC	BLC	4.10	4.10	4.10	BLC	2.30	1.50	BLC	BLC	BLC
ESMP8D	8/20/94	BLC	BLC	BLC	BLC	BLC	0.00	0.00	BLC	BLC	BLC	BLC	BLC	BLC
ESMP9S	8/21/94	BLC	BLC	BLC	3.20	BLC	3.20	3.20	BLC	1.60	1.20	1.00	BLC	BLC
ESMP10S	8/21/94	2.00	2.30	5.60	10.40	3.30	13.70	23.60	35.80	4.80	16.90	BLC	BLC	BLC
ESMP10D	8/21/94	BLC	BLC	BLC	BLC	BLC	BLC	BLC	1.00	1.00	1.00	BLC	BLC	BLC
ESMP11S	8/21/94	BLC	BLC	BLC	2.20	BLC	2.20	2.20	1.10	1.80	1.30	BLC	2.00	BLC
ESMP11D	8/21/94	BLC	1.00	BLC	BLC	BLC	BLC	1.00	BLC	1.00	1.00	BLC	BLC	BLC

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TABLE 4.3 (continued)

FUEL HYDROCARBONS AND CHLORINATED VOCs DETECTED IN GROUND WATER
SITE 3 (FIRE TRAINING AREA) INTRINSIC REMEDIATION TS
MICHIGAN AIR NATIONAL GUARD
W.K. KELLOGG MEMORIAL AIRPORT
BATTLE CREEK, MICHIGAN

Sample Location	Sample Date	Benzene (µg/L)	Toluene (µg/L)	Ethylbenzene (µg/L)	m+p-Xylene (µg/L)	o-Xylene (µg/L)	Total Xylenes (µg/L)	Total BTEX (µg/L)	1,3,5-TMB[a] (µg/L)	1,2,4-TMB[a] (µg/L)	1,2,3-TMB[a] (µg/L)	cis-1,2-DCE[b] (µg/L)	TCE[c] (µg/L)	PCE[d] (µg/L)
ESMP12S	8/21/94	BLC	1.00	BLC	BLC	BLC	BLC	1.00	BLC	1.00	BLC	BLC	2.2	BLC
ESMP12S(D)	8/21/94	BLC	1.00	BLC	BLC	BLC	BLC	1.00	BLC	1.00	1.00	BLC	BLC	2.3	BLC
ESMP12D	8/21/94	BLC	1.00	BLC	1.20	BLC	1.20	2.20	1.00	1.10	1.00	BLC	BLC	BLC
ESMP13S	8/21/94	BLC	BLC	BLC	BLC	BLC	BLC	BLC	BLC	1.00	1.00	BLC	BLC	BLC
ESMP13S(D)	8/21/94	BLC	BLC	BLC	1.00	BLC	1.00	1.00	1.00	1.30	1.40	BLC	BLC	BLC
BC3MW1	8/17/94	BLC	BLC	BLC	BLC	BLC	BLC	BLC	1.00	1.30	1.00	BLC	BLC	BLC
BC3MW1(D)	8/17/94	BLC	BLC	BLC	BLC	BLC	BLC	BLC	BLC	1.00	1.00	BLC	BLC	BLC
BC3MW2	8/17/94	1.60	BLC	5.50	12.80	1.00	13.80	20.90	3.00	15.40	9.50	9.8	BLC	1.1
BC3MW3	8/17/94	BLC	BLC	BLC	BLC	BLC	BLC	BLC	BLC	1.00	1.00	BLC	BLC	1.1
BC3MW4	8/17/94	BLC	BLC	BLC	BLC	BLC	BLC	BLC	BLC	1.00	1.00	BLC	BLC	BLC
BC3MW5	8/18/94	BLC	BLC	BLC	BLC	BLC	BLC	BLC	BLC	1.00	BLC	BLC	BLC	BLC
BC3MW6	8/18/94	BLC	BLC	BLC	BLC	BLC	BLC	BLC	BLC	1.00	1.00	BLC	BLC	BLC
BC3MW6(D)	8/18/94	BLC	BLC	BLC	BLC	BLC	BLC	BLC	BLC	1.00	1.00	BLC	BLC	BLC
BC5MW1	8/18/94	BLC	BLC	BLC	BLC	BLC	BLC	BLC	BLC	1.00	BLC	BLC	BLC	1.0
Vent Well [e]	8/18/94	376.00	1500.00	159.00	916.00	601.00	1517.00	3552.00	99.00	236.00	188.00	1410.0	BLC	1.0

[a] TMB = Trimethylbenzene
[b] DCE = Dichloroethene
[c] TCE = Trichloroethylene
[d] PCE = Tetrachloroethylene
[e] BLC = Below lowest calibration (1 µg/L)
[f] (D) = Duplicate
[g] Vent Well = Bioventing vent well
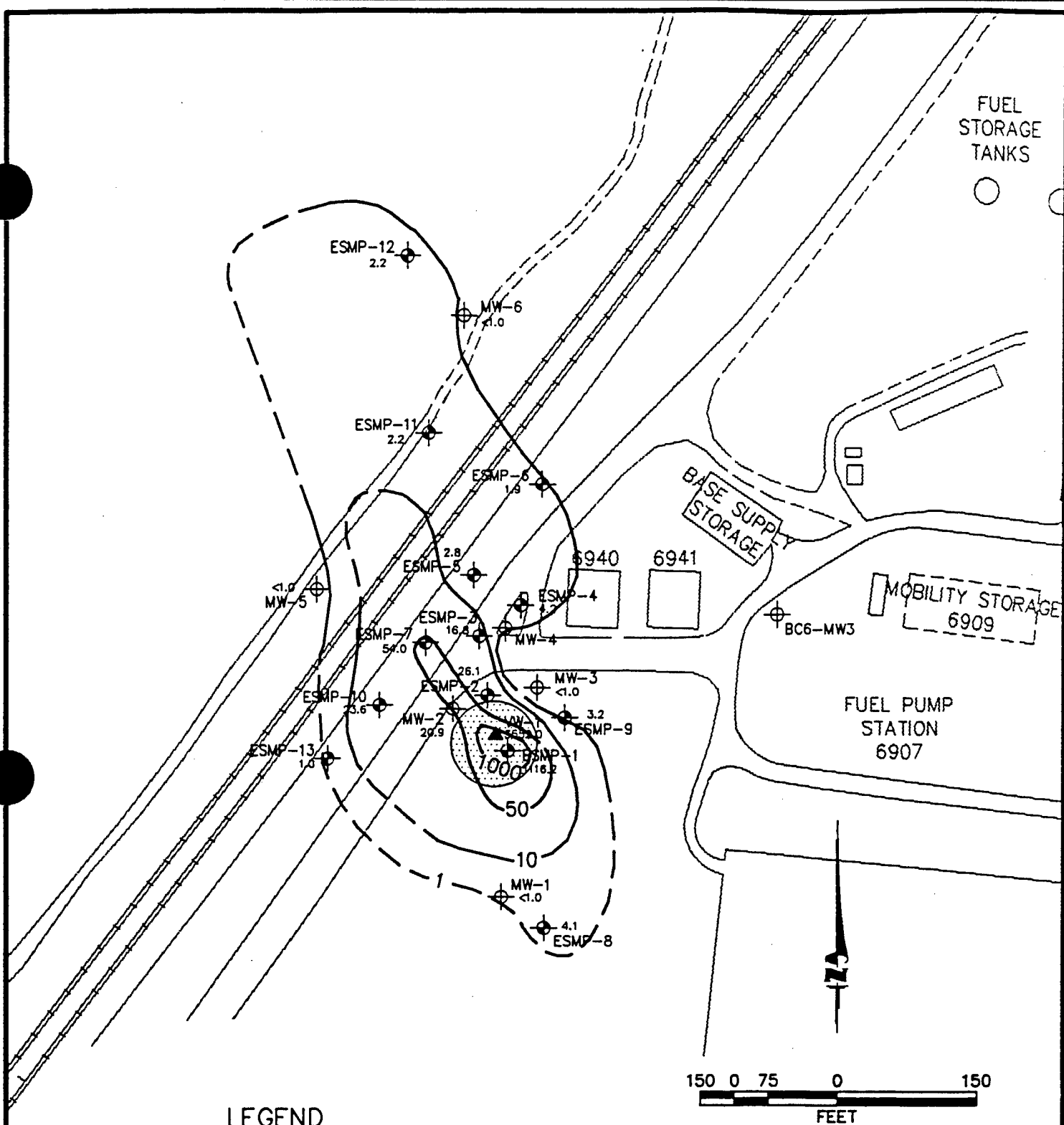
3/13/95

FUEL
STORAGE
TANKS

ESMP-12
2.2

MW-6
<1.0

ESMP-11
2.2

ESMP-6
1.9

BASE SUPPLY STORAGE

6940   6941

ESMP-5
2.8

MW-5
<1.0

ESMP-4
4.1

MOBILITY STORAGE
6909

ESMP-7
54.0

ESMP-3
16.4

MW-4

BC6-MW3

ESMP-2
26.1

MW-3
<1.0

ESMP-10
3.6

MW-2
20.9

VW-1
6542.0

ESMP-9
3.2

FUEL PUMP
STATION
6907

ESMP-13
1.0

ESMP-1
116.2

1000

50

10

1

MW-1
<1.0

ESMP-8
4.1

N

150 0 75   0   150

FEET

LEGEND

ESMP-1   MONITORING POINT

MW-1   MONITORING WELL

VW-1   BIOVENTING VENT WELL

FIRE TRAINING AREA

10   LINE OF EQUAL BTEX CONCENTRATION
(μg/L)(DASHED WHERE INFERRED)

CONTOUR INTERVAL = VARIABLE

FIGURE 4.2

**BTEX ISOPLETHS FOR
GROUND WATER, AUGUST 1994**

Site 3 (Fire Training Area)
Intrinsic Remediation TS
Michigan Air National Guard, W.K. Kellogg Airport
Battle Creek, Michigan

**PARSONS
ENGINEERING SCIENCE, INC.**

Denver, Colorado

Figure 4.3 is a vertical profile through the plume, showing the vertical distribution of contamination.

Dissolved BTEX compounds were detected in monitoring point ESMP-12, which suggests that BTEX has migrated as much as 500 feet downgradient from the fire training pit (Figure 4.2). The dissolved BTEX plume is as much as 900 feet long and 375 feet wide, as defined by the 1 microgram per liter (μg/L) total BTEX isopleth. The highest BTEX concentration of 3,552 μg/L was detected at the bioventing vent well VW-1. As indicated by the vertical profile, detectable concentrations of BTEX were found as deep as 25 feet below the surface of the water table. Total BTEX concentrations of up to 26.1 μg/L were detected 20 feet below the water table in the vicinity of the fire training pit. Downgradient of the fire training pit at monitoring points ESMP-11 and ESMP-12, total dissolved BTEX concentrations did not exceed 2.2 μg/L at any sampled depth. It is likely, based on the vertical profile of BTEX contamination, that the vertical extent of contamination does not exceed 30 feet below the water table at the site.

Generic Type B cleanup criteria are designed such that concentrations of hazardous substances do not pose an unacceptable risk to human health and the environment. These are calculated on the basis of standardized exposure assumptions and acceptable risk levels for unrestricted-use sites as described in the provisions of the Michigan Environmental Response Act (State of Michigan, 1994), and further documented in the Michigan Department of Natural Resources (MDNR) Operational Memorandum #8, Revision 3 (1994). Values of generic Type B cleanup criteria for groundwater have been calculated to provide both a health-based drinking water standard and an aesthetic drinking water standard. MDNR requires that the more restrictive of the health-based and aesthetics criterion be the preferred cleanup criteria for a site (MDNR, 1990). Six monitoring points/wells at five locations in the Fire Training Area had benzene concentrations exceeding the State of Michigan Type B cleanup criteria of 1.2 μg/L. Benzene concentrations at the site ranged from 2 to 276 μg/L, with the maximum concentration detected at the vent well. Toluene exceeded the Type B cleanup criteria of 790 μg/L at the vent well, with a concentration of 1,500 μg/L. Ethylbenzene exceeded the Type B cleanup criteria of 74 μg/L at both monitoring point ESMP-1S and the vent well, with concentrations of 123 μg/L and 100 μg/L, respectively. Total xylenes exceeded the Type B cleanup criteria of 280 μg/L at ESMP-1 (963 μg/L) and at the vent well (1517 μg/L).

Three isomers of trimethylbenzene (TMB) are included in the analytical results for the groundwater samples (Table 4.3). TMB compounds can be recalcitrant under anaerobic conditions and may be useful as a tracer to determine first-order decay rate constants for BTEX. This requires comparison of TMB concentrations and total BTEX concentrations along the flow path at the Site. This technique was not applicable at this Site due to the rapid decrease in BTEX and TMB compounds downgradient of the source area.

4.3.1.2 Chlorinated Volatile Organic Compounds

Groundwater samples collected in 1994 were analyzed for chlorinated VOCs by EPA RSKERL using RSKERL method RSKSOP-148. Analytical results are presented in Table 4.3. PCE was detected in four samples in concentrations ranging from 1.5 μg/L

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FIGURE 4.3
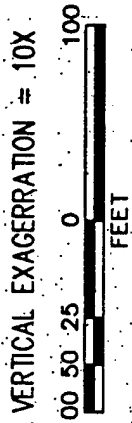
VERTICAL PROFILE OF TOTAL BTEX ISOPLETHS FOR GROUND WATER

Site 3 (Fire Training Area)
Intrinsic Remediation TS
Michigan Air National Guard, W.K. Kellogg Airport
Battle Creek, Michigan

PARSONS
ENGINEERING SCIENCE, INC.

Denver, Colorado

VERTICAL EXAGERRATION ≈ 10X

FEET

LEGEND

MONITORING POINT/WELL IDENTIFICATION

MONITORING POINT/WELL

WATER TABLE ELEVATION

SCREENED INTERVAL WITH TOTAL BTEX CONCENTRATION (μg/L)

LINE OF EQUAL BTEX CONCENTRATION (μg/L)
(DASHED WHERE INFERRED)

CONTOUR INTERVAL = VARIABLE

ELEVATION ABOVE MEAN SEA LEVEL (FEET)

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(ESMP-1S) to 2.5 µg/L (ESMP-3S). TCE was detected in three samples at concentrations ranging from 1.1 µg/L (ESMP-7S) to 2.3 µg/L (ESMP-4D).

4.3.2 Groundwater Geochemistry

Microorganisms obtain energy for cell production and maintenance by facilitating the transfer of electrons from electron donors to electron acceptors. This results in the oxidation of the electron donor and the reduction of the electron acceptor. Electron donors at the Fire Training Area are natural organic carbon and petroleum hydrocarbons. Petroleum hydrocarbons can be completely mineralized or biodegraded if they are utilized as the primary electron donor for microbial metabolism (Bouwer, 1992). Electron acceptors are elements or compounds that occur in relatively oxidized states and include oxygen, nitrate, ferric iron, sulfate, and carbon dioxide. Microorganisms preferentially utilize electron acceptors based on the thermodynamics and availability of electron acceptors. DO is typically utilized first as the prime electron acceptor in aerobic biodegradation. Following the depletion of oxygen, an anaerobic state predominates in which anaerobic microorganisms use the following general order of electron acceptors: nitrate, ferric iron, sulfate, and carbon dioxide.

Depending on the type of electron acceptors present (e.g., nitrate, sulfate, carbon dioxide), pH conditions, and redox potential, anaerobic biodegradation can occur by denitrification, ferric iron reduction, sulfate reduction, or methanogenesis. Other, less common anaerobic degradation mechanisms such as manganese reduction may dominate if the physical and chemical conditions in the subsurface favor the use of these electron acceptors. Anaerobic destruction of the BTEX compounds is associated with the accumulation of fatty acids, production of methane, solubilization of iron, and reduction of nitrate and sulfate (Cozzarelli et al., 1990; Wilson et al., 1990). Environmental conditions and microbial competition will ultimately determine which processes will dominate. Vroblesky and Chapelle (1994) show that the dominant terminal electron accepting process can vary both temporally and spatially in an aquifer with fuel hydrocarbon contamination.

Data for electron acceptors at Site 3 indicate varied degrees of intrinsic remediation of hydrocarbons in the shallow aquifer by aerobic oxidation, denitrification, iron reduction, sulfate reduction, and methanogenesis. Based on stoichiometry and concentrations of methane that occur in areas of highest BTEX contamination, it appears that methanogenesis has the greatest potential as an anaerobic mechanism for BTEX oxidation at the site. However, denitrification, iron reduction, and sulfate reduction have the potential to contribute to nearly 50 percent of BTEX oxidation under anaerobic conditions. As described in the following sections, trends in the concentrations of electron acceptors and biodegradation byproducts provide empirical evidence of anaerobic biodegradation of BTEX compounds.

4.3.2.1 Dissolved Oxygen

Dissolved oxygen measurements were collected at groundwater monitoring points and monitoring wells in August 1994. Table 4.4 summarizes DO concentrations. Figure 4.4 is an isopleth map showing the distribution of DO concentrations in groundwater, and Figure 4.5 is a vertical section through the DO plume. Comparison of Figures 4.2 and 4.4

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TABLE 4.4
GROUND WATER GEOCHEMICAL DATA
SITE 3 (FIRE TRAINING AREA) INTRINSIC REMEDIATION TS
MICHIGAN AIR NATIONAL GUARD
W.K. KELLOGG MEMORIAL AIRPORT
BATTLE CREEK, MICHIGAN

Sample Number	Sample Date	Water Temp. (°C)	pH	Conductivity (µmhos/cm)	Dissolved Oxygen (mg/L)	Redox Potential (mV)	Total Alkalinity (mg/L)	Hydrogen Sulfide (mg/L)	Ferrous Iron (mg/L)	Chloride (mg/L)	Sulfate (mg/L)	NO₂+NO₃ Nitrogen (mg/L)	TOC [c] (mg/L)	Methane (mg/L)
ESMP-1S	8/19/94	19.1	6.79	917	0.12	-143.0	670	0.1	10.0	2.64	2.7	<0.05	53.9	4.228
ESMP-1D	8/19/94	15.8	7.61	454	0.81	-110.9	200	NA[b]	<0.1	1.77	7.96	2.49	0.7	0.004
ESMP-2S	8/19/94	16.7	8.08	532	0.86	-97.2	252	NA	2.0	1.51	5.6	1.27	2.0	0.066
ESMP-2D	8/19/94	14.8	7.54	466	0.1	-238.0	212	NA	0.6	2.05	14.7	1.24	0.7	0.003
ESMP-3S	8/19/94	15.8	7.78	399	4.41	26.0	166	<0.1	0.1	6.68	12.8	1.48	0.9	BLQ[d]
ESMP-3S(D)[d]		NA	NA	NA	NA	NA	NA	NA	NA	6.79	12.8	NA	NA	NA
ESMP-3D	8/19/94	15.8	7.73	409	0.33	-203.1	186	NA	0.2	2.07	8.59	2.24	0.7	0.003
ESMP-3DD	8/20/94	13.8	7.42	564	0.09	<-200.9	264	NA	3.0	5.57	23.7	<0.05	0.7	0.004
ESMP-4S	8/20/94	13.2	6.86	390	4.45	195.0	158	NA	<0.1	3.65	11.7	3.42	0.6	ND[d]
ESMP-4S(D)		NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	3.4	NA	NA
ESMP-4D	8/20/94	12.7	8.93	455	3.99	-10.9	212	NA	<0.1	1.96	10.4	2	0.6	0.001
ESMP-5S	8/20/94	20.4	8.25	340	6.11	48.2	132	NA	<0.1	12.8	9.7	0.31	5.2	0.007
ESMP-5D	8/20/94	13.6	7.31	438	0.25	-81.5	200	NA	<0.1	2.54	8.52	1.98	0.7	0.015
ESMP-5D(D)		NA	NA	436	NA	NA	200	NA	NA	NA	NA	NA	NA	NA
ESMP-6S	8/20/94	13.7	7.4	513	5.44	194.0	226	NA	<0.1	6.61	12.3	2.23	0.5	BLQ
ESMP-6D	8/20/94	13	7.45	518	5.06	-6.7	232	NA	<0.1	7.36	13.1	2.5	0.5	0.003
ESMP-7S	8/20/94	17.2	7.28	600	0.27	-132.2	274	0.1	5.0	7.21	6.45	1.34	15.6	0.829
ESMP-7S(D)		NA	NA	NA	NA	NA	NA	NA	NA	7.12	6.36	NA	NA	NA
ESMP-7D	8/20/94	14.2	7.25	480	0.7	-160.0	232	NA	4.0	2.72	12	0.06	3.1	0.165
ESMP-7D(D)		NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	0.05	NA	NA
ESMP-8S	8/20/94	13.7	7.44	595	5.62	-70.0	286	NA	0.2	1.86	13.2	1.31	0.5	0.003
ESMP-8D	8/20/94	13.7	7.57	490	0.7	-95.0	228	NA	2.0	2.85	17.9	0.52	2.8	0.002
ESMP-9S	8/21/94	12.6	7.21	551	0.18	<-335	284	NA	0.1	2.44	1.82	0.06	1.1	0.157
ESMP-10S	8/20/94	13	7.27	626	0.32	<-314	282	NA	10.0	4.54	3.56	<0.05	6.9	0.614
ESMP-10S(D)		NA	NA	NA	NA	NA	NA	NA	NA	4.48	3.45	NA	NA	NA
ESMP-10D	8/21/94	13.2	7.68	467	2.37	-81.0	318	NA	0.2	3.25	13.2	1	12.4	0.003
ESMP-10D(D)		NA	NA	467	NA	NA	320	NA	NA	NA	NA	NA	0.6	NA
ESMP-11S	8/21/94	12.4	7.63	479	6.6	103.6	210	NA	NA	11.9	15.8	1.5	1.4	BLQ

L:\45010\tables\TABLE4-4.XLS

3/10/95

TABLE 4.4 (Continued)
GROUND WATER GEOCHEMICAL DATA
SITE 3 (FIRE TRAINING AREA) INTRINSIC REMEDIATION TS
MICHIGAN AIR NATIONAL GUARD
W.K. KELLOGG MEMORIAL AIRPORT
BATTLE CREEK, MICHIGAN

Sample Number	Sample Date	Water Temp. (°C)	pH	Conductivity (µmhos/cm)	Dissolved Oxygen (mg/L)	Redox Potential (mV)	Total Alkalinity (mg/L)	Hydrogen Sulfide (mg/L)	Ferrous Iron (mg/L)	Chloride (mg/L)	Sulfate (mg/L)	NO_2+NO_3 Nitrogen (mg/L)	TOC [a] (mg/L)	Methane (mg/L)
ESMP-11D	8/21/94	13.5	7.66	412	0.1	<-170	212	NA	NA	1.8	15.6	0.4	4.2	0.002
ESMP-12S	8/21/94	12.4	7.57	467	4.44	65.2	204	NA	NA	5.21	12.7	1.5	1.2	0.002
ESMP-12D	8/21/94	17.5	7.48	547	1.3	-95.5	260	NA	NA	5.05	27.3	NA	2.1	0.003
ESMP-13S	8/21/94	13.1	7.4	588	6.87	70.7	302	NA	0.1	2.72	8.73	1	1.0	0.003
BC3-MW1	8/17/94	14.4	7.42	528	0.12	-60.0	254	NA	1.5	4.64	21.8	<0.05	3.0	0.002
BC3-MW2	8/17/94	15.3	7.67	460	0.12	-60.0	212	<0.1	3.0	2.14	15	<0.05	5.0	0.393
BC3-MW3	8/17/94	13.6	7.68	421	0.1	180.0	174	NA	<0.1	1.77	9.81	1	0.3	BLQ
BC3-MW4	8/17/94	13.8	7.51	495	0.27	-14.7	224	NA	0.2	2.9	22.8	0.06	0.9	BLQ
BC3-MW5	8/18/94	12.7	7.36	440	5.78	255.0	194	NA	<0.1	1.65	11.1	2.13	19.0	ND
BC3-MW6	8/18/94	14.3	7.12	545	0.1	-106.1	248	NA	3.0	4.7	22.9	0.05	1.9	BLQ
BC5-MW1	8/18/94	14.4	7.08	565	1.92	219.2	260	<0.1	<0.1	2.24	12.7	1.95	1.0	ND
BC5-MW1(D)		NA	NA	NA	NA	NA	NA	NA	NA	2.26	12.8	NA	NA	NA
VW	8/18/94	21.5	6.76	1030	0.14	-99.5	492	0.2	12.0	6	7.5	<0.05	253.0	8.397
VW-3(D)		NA	NA	NA	NA	NA	NA	NA	NA	5.86	7.42	NA	253.0	NA

[a] TOC = Total organic carbon.
[b] NA = Not available.
[c] BLQ = Below lower limit of quantitation (0.001 mg/L)
[d] (D) = Duplicate
[e] ND = Not detected
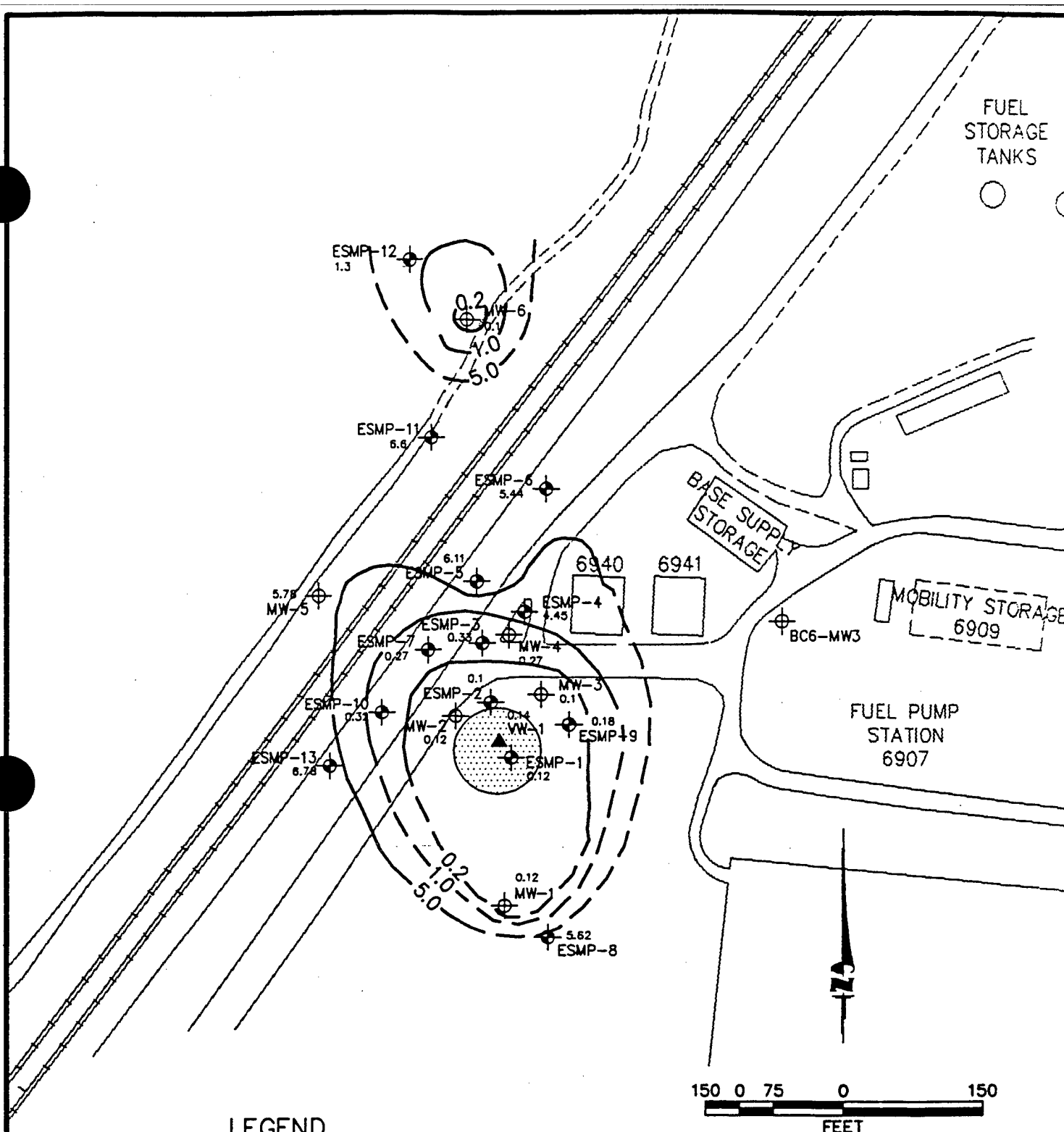
I:\M5010\tables\TABLE4-4.XLS

FUEL
STORAGE
TANKS

ESMP-12
1.3

0.2
MW-6
0.1
1.0
5.0

ESMP-11
6.6

ESMP-6
5.44

BASE SUPPLY
STORAGE

6940   6941

6.11
ESMP-5

5.78
MW-5

ESMP-4
4.45

ESMP-3
0.33
ESMP-7
0.27
MW-4
0.27

MOBILITY STORAGE
6909

BC6-MW3

0.1
MW-3
ESMP-2
0.1
0.1

ESMP-10
0.32

0.14
MW-2
VW-1
0.12
ESMP-1
0.12

0.18
ESMP-9

FUEL PUMP
STATION
6907

ESMP-13
6.78

0.2
1.0
5.0

0.12
MW-1

N

5.62
ESMP-8

150 0 75   0   150

FEET

LEGEND

ESMP-1   MONITORING POINT

MW-1   MONITORING WELL

▲ VW-1   BIOVENTING VENT WELL

          FIRE TRAINING AREA

5.0   LINE OF EQUAL DO CONCENTRATION
          (mg/L)(DASHED WHERE INFERRED)

CONTOUR INTERVAL = VARIABLE

FIGURE 4.4

**DISSOLVED OXYGEN
ISOPLETHS FOR GROUND WATER
AUGUST 1994**

Site 3 (Fire Training Area)
Intrinsic Remediation TS
Michigan Air National Guard, W.K. Kellogg Airport
Battle Creek, Michigan

**PARSONS
ENGINEERING SCIENCE, INC.**

Denver, Colorado

FIGURE 4.5

VERTICAL PROFILE OF DISSOLVED OXYGEN ISOPLETHS FOR GROUND WATER

Site 3 (Fire Training Area)
Intrinsic Remediation TS
Michigan Air National Guard, W.K. Kellogg Airport
Battle Creek, Michigan

PARSONS
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Denver, Colorado

VERTICAL EXAGGERATION = 10X

HORIZONTAL 100 50 25 0 100 FEET
VERTICAL 10 0 10 FEET

LEGEND

MONITORING POINT/WELL IDENTIFICATION

MONITORING POINT/WELL
WATER TABLE ELEVATION

2.20 SCREENED INTERVAL WITH DISSOLVED OXYGEN CONCENTRATION (mg/L)

~2.0~ LINE OF EQUAL DISSOLVED OXYGEN CONCENTRATION (mg/L)
(DASHED WHERE INFERRED)

CONTOUR INTERVAL = VARIABLE

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and Figures 4.3 and 4.5 shows that areas with elevated total BTEX concentrations correlate with areas with depleted DO concentrations. Dissolved oxygen concentrations vary from 6.87 mg/L to 0.09 mg/L at the site, indicating that aerobic biodegradation of BTEX contamination is occurring.

Dissolved oxygen concentrations are depleted near the fire training pit at Site 3 (Figure 4.4). The apparent separation of the depleted DO plumes in the vicinity of the fire training pit and downgradient of the pit is a result of mapping the electron acceptor concentrations at the same level from which the sample with the highest BTEX concentration was collected. Comparison of the vertical profile of DO concentrations (Figure 4.5) and the vertical profile of BTEX contamination (Figure 4.3) shows excellent correlation between areas of depleted DO and areas of elevated BTEX, indicating consumption of DO by aerobic organisms within the BTEX plume. Dissolved oxygen concentrations nearer background levels in the shallower portion of the aquifer downgradient from the source area may reflect the infiltration of aerated water. The area northwest of the fire training pit is generally undeveloped and vegetated, thus allowing recharge to occur.

The following equations describe the overall stoichiometry of aerobic mineralization of benzene. In the absence of microbial cell production, the oxidation (mineralization) of benzene to carbon dioxide and water is given by:

$$C_6H_6 + 7.5O_2 \rightarrow 6CO_2 + 3H_2O$$
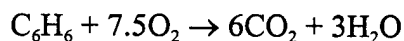
Therefore, 7.5 moles of oxygen are required to metabolize 1 mole of benzene. On a mass basis, the ratio of oxygen to benzene is given by:

Molecular weights: Benzene $6(12) + 6(1) = 78$ gm/mole

                      Oxygen $7.5(32) = 240$ gm/mole

Mass Ratio of Oxygen to Benzene = 240/78 = 3.08:1

Therefore, in the absence of microbial cell production, 3.08 mg of oxygen are required to completely metabolize 1 mg of benzene.

Similar calculations can be completed for toluene (3.13 oxygen to 1 toluene), ethylbenzene (3.17 oxygen to 1 ethylbenzene), and the xylenes (3.17 oxygen to 1 xylene). The average mass ratio of oxygen to one part total BTEX is thus 3.14:1. This means that approximately 0.32 mg of BTEX is mineralized for every 1.0 mg of DO consumed. With a maximum background DO concentration of approximately 5.6 mg/L, shallow groundwater replenishing this site from upgradient sources has the capacity to assimilate 1.8 mg/L (1,800 µg/L) of total BTEX. This is a conservative estimate of the assimilative capacity of DO because microbial cell mass production was not taken into account by the stoichiometry shown above.

When cell mass production is accounted for, the mineralization of benzene to carbon dioxide and water is given by:

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$$C_6H_6 + 2.5O_2 + HCO_3 + NH_4 \rightarrow C_5H_7O_2N + 2CO_2 + 2H_2O$$

From this it can be seen that only 2.5 moles of DO are required to mineralize 1 mole of benzene when cell mass production is taken into account. On a mass basis, the ratio of DO to benzene is given by:

Molecular weights: Benzene $6(12) + 6(1) = 78$ gm/mole

Oxygen $2.5(32) = 80$ gm/mole

Mass Ratio of Oxygen to Benzene = $80/78 = 1.03:1$

On the basis of these stoichiometric relationships, 1.03 mg of oxygen are required to mineralize 1 mg of benzene. Similar calculations can be made for toluene, ethylbenzene, and the xylenes. Based on these calculations, approximately 0.97 mg of BTEX is mineralized to carbon dioxide and water for every 1.0 mg of DO consumed. With a maximum upgradient background DO concentration of approximately 5.6 mg/L, the shallow groundwater at this site has the capacity to assimilate 5.4 mg/L (5,400 µg/L) of total BTEX if microbial cell mass production is taken into account.

4.3.2.2 Nitrate/Nitrite

Concentrations of nitrate + nitrite (as nitrogen) were measured at groundwater monitoring points and monitoring wells in August 1994. Nitrate + nitrite concentrations at the site varied from 3.42 mg/L to less than 0.05 mg/L. Measured nitrate and nitrite concentrations are presented in Table 4.4. Shallow groundwater at the site exhibits a pattern of reduced nitrate + nitrite concentrations in areas of elevated total BTEX concentrations. This trend is illustrated by comparison of Figure 4.6 with Figure 4.2. Comparison of nitrate + nitrite concentrations (Figure 4.6) with DO concentrations (Figure 4.4) reveals that areas with depleted levels of DO are generally depleted in nitrate + nitrite as well. This indicates that anaerobic biodegradation of dissolved BTEX is occurring through denitrification in these areas.

In the absence of microbial cell production, the biodegradation of benzene via denitrification to carbon dioxide and water is given by:

$$6NO_3^- + 6H^+ + C_6H_6 \rightarrow 6CO_{2(g)} + 6H_2O + 3N_{2(g)}$$
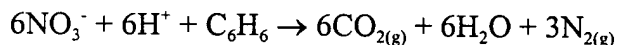
According to this relationship, 6 moles of nitrate are required to mineralize 1 mole of benzene. On a mass basis, the ratio of nitrate to benzene is given by:

Molecular weights: Benzene $6(12) + 6(1) = 78$ gm/mole

Nitrate $6(62) = 372$ gm/mole

Mass ratio of nitrate to benzene = $372/78 = 4.77:1$

In the absence of microbial cell production, 4.77 mg of nitrate are required to completely mineralize 1 mg of benzene. Similar calculations can be completed for

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LEGEND

⊕ESMP-1 MONITORING POINT

⊕MW-1 MONITORING WELL

▲VW-1 BIOVENTING VENT WELL

▦ FIRE TRAINING AREA

⌒3.0⌒ LINE OF EQUAL NITRATE + NITRITE
CONCENTRATION (mg/L)
(DASHED WHERE INFERRED)

CONTOUR INTERVAL = VARIABLE

FIGURE 4.6

**NITRATE + NITRITE (AS N)
ISOPLETHS FOR GROUND WATER
AUGUST 1994**

Site 3 (Fire Training Area)
Intrinsic Remediation TS
Michigan Air National Guard, W.K. Kellogg Airport
Battle Creek, Michigan

**PARSONS
ENGINEERING SCIENCE, INC.**

Denver, Colorado
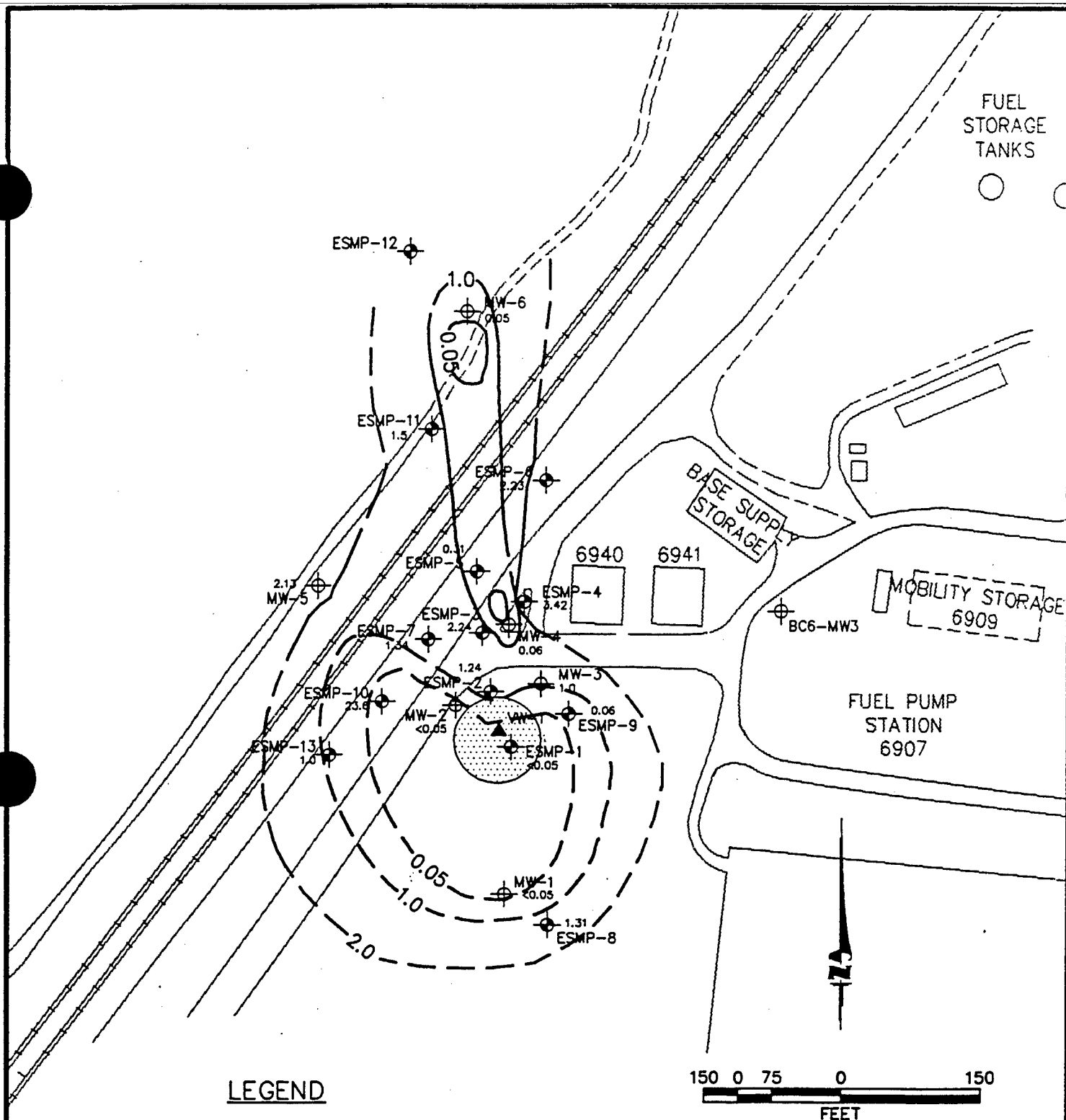
toluene (4.85 mg nitrate to 1 mg toluene), ethylbenzene (4.92 mg nitrate to 1 mg ethylbenzene), and the xylenes (4.92 mg nitrate to 1 mg xylene). The average mass ratio of nitrate consumed to total BTEX degraded is 4.9:1. This means that approximately 0.20 mg of BTEX is mineralized for every 1.0 mg of nitrate consumed. Assuming that the maximum upgradient background nitrate concentration is indicated by the measurement of 1.31 mg/L of nitrate + nitrite at ESMP-8S, the shallow groundwater at this site has the capacity to assimilate 0.26 mg/L (260 µg/L) of total BTEX through denitrification. This is a conservative estimate of the assimilative capacity of nitrate because microbial cell mass production has not been taken into account by the stoichiometry shown above (see Section 4.3.2.1).

4.3.2.3 Ferrous Iron

Ferrous iron concentrations were measured at groundwater monitoring points and monitoring wells in August 1994. Table 4.4 summarizes ferrous iron concentrations. Figure 4.7 is an isopleth map showing the distribution of ferrous iron in groundwater. Comparison of Figures 4.7 and 4.2 graphically shows a correlation between elevated BTEX concentrations and elevated ferrous iron concentrations. This suggests that ferric iron is being reduced to ferrous iron during the degradation of BTEX compounds through microbiologically mediated iron reduction. The highest measured ferrous iron concentration, 12 mg/L, was observed at the bioventing vent well location, which is also the location of the highest detected BTEX concentration. Background levels of ferrous iron are generally at or below 0.1 mg/L, as measured at wells with little or no BTEX contamination.

The following equations describe the overall stoichiometry of benzene oxidation by iron reduction caused by anaerobic microbial biodegradation. In the absence of microbial cell production, the mineralization of benzene is given by:

$$60H^+ + 30Fe(OH)_{3,a} + C_6H_6 \rightarrow 6CO_2 + 30Fe^{2+} + 78H_2O$$
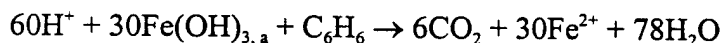
Therefore, 30 moles of ferric iron are required to metabolize 1 mole of benzene. On a mass basis, the ratio of ferric iron to benzene is given by:

Molecular weights:	Benzene	$6(12) + 6(1) = 78$ gm/mole
	Ferric Iron	$30(106.85) = 3205.41$ gm/mole

Mass ratio of ferric iron to benzene = 3205.41/78 = 41.1:1

Therefore, in the absence of microbial cell production, 41.1 mg of ferric iron are required to completely metabolize 1 mg of benzene. Alternatively, the mass ratio of ferrous iron produced during respiration to benzene degraded can be calculated and is given by:

Molecular weights:	Benzene	$6(12) + 6(1) = 78$ gm/mole
	Ferrous Iron	$30(55.85) = 1675.5$ gm/mole

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LEGEND

⊕ ESMP-1   MONITORING POINT

⊕ MW-1   MONITORING WELL

▲ VW-1   BIOVENTING VENT WELL

▨   FIRE TRAINING AREA

⌇ 5 ⌇   LINE OF EQUAL FERROUS IRON
         CONCENTRATION (mg/L)
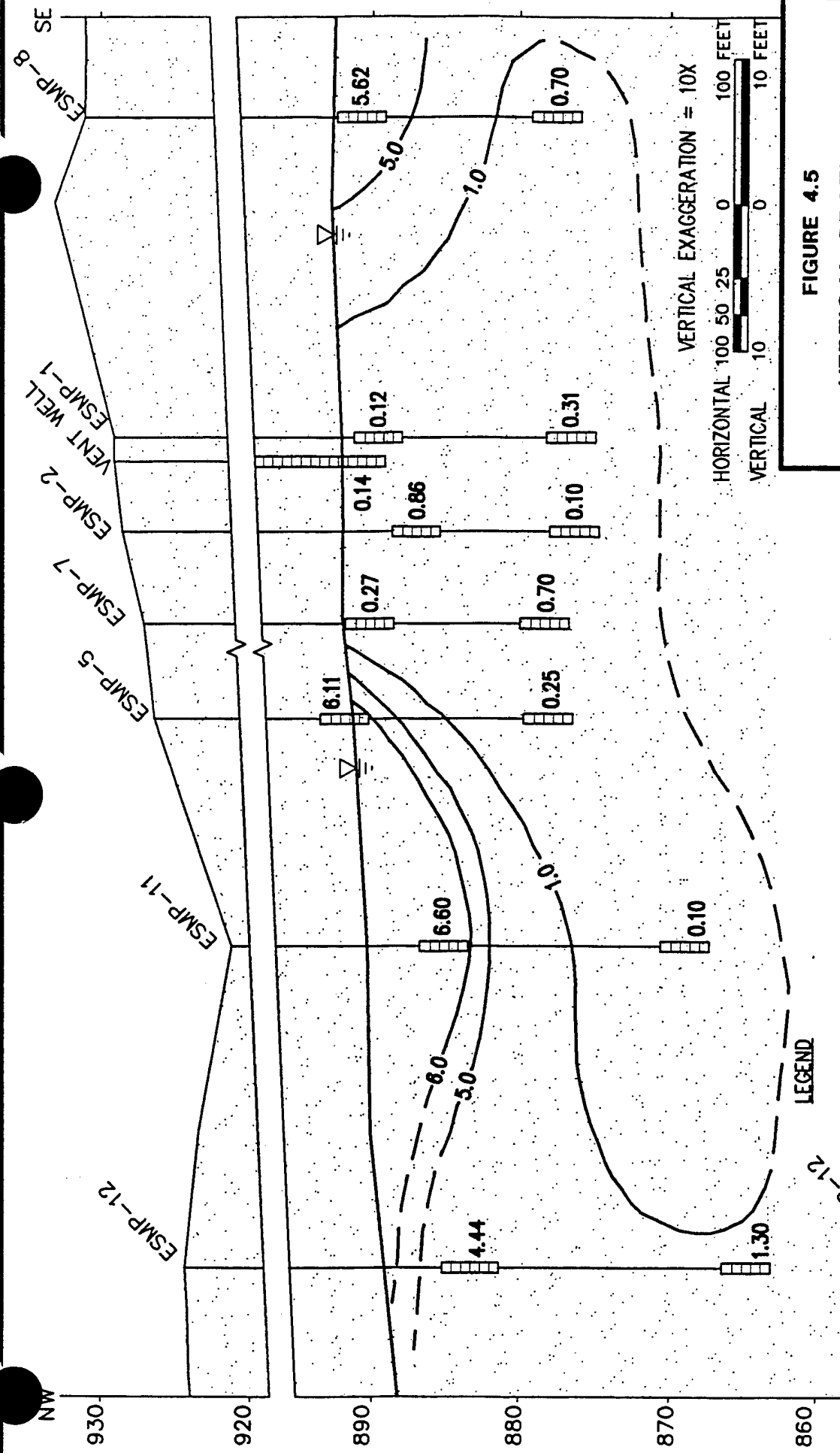   (DASHED WHERE INFERRED)

CONTOUR INTERVAL = VARIABLE

FIGURE 4.7

**FERROUS IRON ISOPLETHS
FOR GROUND WATER**

Site 3 (Fire Training Area)
Intrinsic Remediation TS
Michigan Air National Guard, W.K. Kellogg Airport
Battle Creek, Michigan

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Mass ratio of ferrous iron to benzene = 1675.5/78 = 21.5:1

Therefore, 21.5 mg of ferrous iron are produced during mineralization of 1 mg of benzene.

Similar calculations can be completed for toluene (21.86 mg of Fe^{2+} produced during mineralization of 1 mg of toluene), ethylbenzene (22 mg of Fe^{2+} produced during mineralization of 1 mg of ethylbenzene), and the xylenes (22 mg of Fe^{2+} produced during mineralization of 1 mg of xylene). The average mass ratio of Fe^{2+} produced during total BTEX mineralization is thus 21.8:1. This means that approximately 1 mg of BTEX is mineralized for every 21.8 mg of Fe^{2+} produced. The highest measured Fe^{2+} concentration was 12.0 mg/L. This suggests that the shallow groundwater at this site has the capacity to assimilate 0.55 mg/L (550 µg/L) of total BTEX during iron reduction. This is a conservative estimate of the assimilative capacity of iron because microbial cell mass production has not been taken into account by the stoichiometry shown above (see Section 4.3.2.1). In addition, this calculation is based on observed ferrous iron concentrations and not on the amount of ferric hydroxide available in the aquifer. Therefore, iron assimilative capacity could be much higher.

4.3.2.4 Sulfate

Sulfate concentrations were measured at groundwater monitoring points and monitoring wells in August 1994. Table 4.4 summarizes measured sulfate concentrations. Sulfate concentrations vary from 27.3 mg/L to 2.7 mg/L, and in general, low sulfate concentrations coincide with elevated BTEX concentrations. These trends can be seen by comparison of the distribution of sulfate (Figure 4.8) with that of dissolved BTEX (Figure 4.2). In addition, decreased DO concentrations in the groundwater (Figure 4.4) correspond to decreased sulfate concentrations. These trends are strong indicators that anaerobic biodegradation of BTEX compounds is occurring in certain areas at the site through the microbially mediated process of sulfate reduction. Although sulfate reduction appears to be occurring over most of the contaminated area at the site, several locations exhibit both elevated BTEX and high sulfate concentrations (e.g., ESMP-2, MW-2).

The following equations describe the overall stoichiometry of BTEX oxidation by sulfate reduction caused by anaerobic microbial biodegradation. In the absence of microbial cell production, the biodegradation of benzene is given by:

$$7.5H^+ + 3.75SO_4^{2-} + C_6H_6 \rightarrow 6CO_{2(g)} + 3.75H_2S^\circ + 3H_2O$$
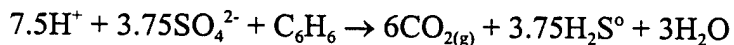
Therefore, 3.75 moles of sulfate are required to mineralize 1 mole of benzene. On a mass basis, the ratio of sulfate to benzene is given by:
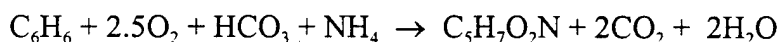
| Molecular weights: | Benzene | $6(12) + 6(1) = 78$ gm/mole |
| | Sulfate | $3.75(96) = 360$ gm/mole |

Mass ratio of sulfate to benzene = 360/78 = 4.6:1

LEGEND

ϕ ESMP-1 MONITORING POINT

ϕ MW-1 MONITORING WELL

▲ VW-1 BIOVENTING VENT WELL

[   ] FIRE TRAINING AREA

— 5 — LINE OF EQUAL SULFATE
CONCENTRATION (mg/L)
(DASHED WHERE INFERRED)

CONTOUR INTERVAL = VARIABLE

FIGURE 4.8

**SULFATE ISOPLETHS
FOR GROUND WATER
AUGUST 1994**

Site 3 (Fire Training Area)
Intrinsic Remediation TS
Michigan Air National Guard, W.K. Kellogg Airport
Battle Creek, Michigan

**PARSONS
ENGINEERING SCIENCE, INC.**

Denver, Colorado

Therefore, in the absence of microbial cell production, 4.6 mg of sulfate are required to completely mineralize 1 mg of benzene. Similar calculations can be completed for toluene (4.7 mg sulfate to 1 mg toluene), ethylbenzene (4.75 mg sulfate to 1 mg ethylbenzene), and the xylenes (4.75 mg sulfate to 1 mg xylene). The average mass ratio of sulfate to total BTEX is thus 4.7:1. This means that approximately 0.21 mg of BTEX is mineralized for every 1.0 mg of sulfate consumed. Assuming a maximum background sulfate concentration of 13.2 mg/L, the shallow groundwater at this site has the capacity to assimilate 2.8 mg/L (2800 μg/L) of total BTEX during sulfate reduction. Again, this is a conservative estimate of the assimilative capacity of sulfate because microbial cell mass production has not been taken into account by the stoichiometry shown above (see Section 4.3.2.1).

4.3.2.5 Methane

Methane concentrations were measured at groundwater monitoring points and monitoring wells in August 1994. Measured concentrations of methane are included in Table 4.4. Figure 4.9 is an isopleth map showing the distribution of methane in groundwater. Based on Figure 4.9, it appears that methane occurs above background only in areas with the highest of BTEX concentrations in groundwater. Hence, elevated methane concentrations extend from the fire training pit down-gradient to approximately ESMP-7. Comparison of Figures 4.2 and 4.9 shows graphically that areas with elevated total BTEX concentrations correlate with elevated methane concentrations. This is a strong indication that anaerobic biodegradation of BTEX compounds through methanogenesis is occurring in the central portion of the BTEX plume.

Background concentrations of methane at wells and monitoring points located outside or below areas with known BTEX contamination are below 0.1 mg/L. Samples collected from monitoring wells or points located near the contaminant source area contained the highest methane concentrations. In these locations, methane concentrations range from about 0.4 to 8.4 mg/L. The highest concentration of methane (8.4 mg/L) was observed at the bioventing vent well in the center of the fire training pit.

The following equations describe the overall stoichiometry of benzene oxidation by methanogenesis. In the absence of microbial cell production, the mineralization of benzene is given by:

$$C_6H_6 + 4.5H_2O \rightarrow 2.25CO_2 + 3.75CH_4$$
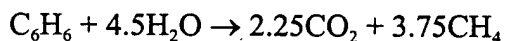
The mass ratio of methane produced during respiration to benzene degraded can be calculated and is given by:

| Molecular weights: | Benzene | $6(12) + 6(1) = 78$ gm/mole |
| | Methane | $3.75(16) = 60$ gm/mole |

Mass ratio of methane to benzene = 60/78 = 0.77:1

Therefore, 0.77 mg of methane is produced during mineralization of 1 mg of benzene.

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LEGEND

$\oplus$ ESMP-1   MONITORING POINT

$\oplus$ MW-1   MONITORING WELL

▲ VW-1   BIOVENTING VENT WELL

[shaded box]   FIRE TRAINING AREA

⌒ 0.1 ⌒   LINE OF EQUAL METHANE
CONCENTRATION (mg/L)
(DASHED WHERE INFERRED)

CONTOUR INTERVAL = VARIABLE

FIGURE 4.9

METHANE ISOPLETHS
FOR GROUND WATER
AUGUST 1994

Site 3 (Fire Training Area)
Intrinsic Remediation TS
Michigan Air National Guard, W.K. Kellogg Airport
Battle Creek, Michigan

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Similar calculations can be completed for toluene (0.78 mg of methane produced during mineralization of 1 mg of toluene), ethylbenzene (0.79 mg of methane produced during mineralization of 1 mg of ethylbenzene), and the xylenes (0.79 mg of methane produced during mineralization of 1 mg of xylene). The average mass ratio of methane produced during total BTEX mineralization is thus 0.78:1. This means that approximately 1 mg of BTEX is mineralized for every 0.78 mg of methane produced. The highest measured methane concentration was 8.4 mg/L at the vent well. This suggests that the shallow groundwater at this site has the capacity to assimilate up to 10.8 mg/L (10,800 µg/L) of total BTEX during methanogenesis. Again, this is a conservative estimate of the assimilative capacity of methanogenesis because microbial cell mass production is not taken into account by the stoichiometry shown above (see Section 4.3.2.1). In addition, these calculations are based on observed methane concentrations and not on the amount of carbon dioxide (the electron acceptor) available in the aquifer. Therefore, methanogenic assimilative capacity could be much higher.

4.3.2.6 Reduction/Oxidation Potential

Redox potentials were measured at groundwater monitoring points and monitoring wells in August 1994. Redox potential is a measure of electron activity and is an indicator of the relative tendency of a solution to accept or transfer electrons. The redox potential of a groundwater system influences and is influenced by biodegradation rates. The redox potentials at Site 3 range from 255 millivolts (mV) to -335 mV. Table 4.4 summarizes available redox potential data. Figure 4.10 is a map that graphically illustrates the distribution of redox potentials. Redox potentials are below -100 mV in the vicinity of ESMP-1, ESMP-2, ESMP-3, ESMP-7, ESMP-9, and ESMP-10. Areas at the site with low redox potentials generally coincide with areas of high BTEX contamination, low DO, reduced nitrate + nitrite concentrations, elevated ferrous iron concentrations, reduced sulfate concentrations, and elevated methane concentrations (compare Figures 4.2, 4.4, 4.6, 4.7, 4.8, and 4.9).

4.3.2.7 Alkalinity

Total alkalinity (as calcium carbonate) was measured at groundwater monitoring points and monitoring wells in August 1994. These measurements are summarized in Table 4.4. Alkalinity is a measure of a groundwater's ability to buffer changes in pH caused by the addition of acids. Such acids are typically generated by biologically mediated processes. Total alkalinity at the site is in the low to moderate range for groundwater, and varies from 132 mg/L at ESMP-5S to 670 mg/L at ESMP-1S. This amount of alkalinity should be sufficient to buffer potential changes in pH caused by biologically mediated BTEX oxidation reactions.

4.3.2.8 pH

Groundwater pH was measured at monitoring points and monitoring wells in August 1994. These measurements are summarized in Table 4.4. The pH of a solution is the negative logarithm of the hydrogen ion concentration [H^+]. Groundwater pH at Site PST-29 ranges from 6.8 to 8.9. Most groundwater samples had pH values of 7.2 to 7.7, within the optimal pH range of 6 to 8 for BTEX-degrading microbes.

FUEL
STORAGE
TANKS

ESMP-12
-95.5

MW-16
-105.1

ESMP-11
103.6

ESMP-6
194

BASE SUPPLY
STORAGE

6940   6941

48.2
ESMP-5

255
MW-5

ESMP-4
95

MOBILITY STORAGE
6909

ESMP-7
-132.2

ESMP-3
-203.1

MW-
-147

BC6-MW3

-238
ESMP-2

MW-3
-0.001

ESMP-10
<-314

MW-
-60

VW-

<-335
ESMP-9

FUEL PUMP
STATION
6907

ESMP-13
70.7

ESMP-1
-143

-100 -60

MW-1

-70.0
ESMP-8

0

100

200

N

150 0 75   0   150

FEET

LEGEND

⊕ ESMP-1   MONITORING POINT

⊕ MW-1   MONITORING WELL

▲ VW-1   BIOVENTING VENT WELL

▨   FIRE TRAINING AREA

⌇3.0⌇   LINE OF EQUAL REDOX POTENTIAL (mV)
            (DASHED WHERE INFERRED)

CONTOUR INTERVAL = 100mV

FIGURE 4.10

**REDOX POTENTIAL ISOPLETHS
FOR GROUND WATER
AUGUST 1994**

Site 3 (Fire Training Area)
Intrinsic Remediation TS
Michigan Air National Guard, W.K. Kellogg Airport
Battle Creek, Michigan

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4.3.2.9 Temperature

Groundwater temperature was measured at groundwater monitoring points and monitoring wells in August 1994. Table 4.4 summarizes groundwater temperature readings. Temperature affects the types and growth rates of bacteria that can be supported in the groundwater environment, with higher temperatures generally resulting in higher growth rates. Temperatures in the shallow saturated zone varied from 12.4 °C to 21.5°C. Most groundwater temperatures ranged from 12°C to 16°C except at monitoring points and wells close to the bioventing unit. Monitoring point ESMP-1S and the bioventing well (VW-3) exhibited elevated groundwater temperatures (up to 21.5°C) as a result of warm air injection into the subsurface. As air passes through the bioventing blower, its temperature generally increases 20°-30°C. These are relatively high temperatures for shallow groundwater, suggesting that bacterial growth rates near the vent well could be higher.

4.3.3 Expressed Assimilative Capacity

The data presented in the preceding sections strongly indicate that mineralization of BTEX compounds is occurring through the microbially mediated processes of aerobic respiration, denitrification, iron reduction, sulfate reduction, and methanogenesis. Based on the stoichiometry presented in these sections, the expressed BTEX assimilative capacity of groundwater at Site 3 is at least 16,210 µg/L (Table 4.5). The calculations presented in these earlier sections are conservative because they do not account for microbial cell mass production. In addition, the measured concentrations of ferrous iron and methane may not be the maximum achievable. The highest dissolved total BTEX concentration observed at the site was 3,552 µg/L, detected in the sample from the bioventing vent well in August 1994.

Based on the calculations presented in the preceding sections, and on site observations, groundwater at Site 3 should have sufficient assimilative capacity to degrade dissolved BTEX that partitions from the residual phase into the groundwater

before the plume migrates 1,250 feet towards the northwestern perimeter of the Base. These calculations are conservative in that the DO, nitrate/nitrite, and sulfate values used for the calculations are not the highest observed values at the Site, but are the values from monitoring point ESMP-8, upgradient from the Fire Training Area.

TABLE 4.5
EXPRESSED ASSIMILATIVE CAPACITY OF SITE GROUNDWATER
SITE 3 (FIRE TRAINING AREA) INTRINSIC REMEDIATION TS
MICHIGAN AIR NATIONAL GUARD
W.K. KELLOGG MEMORIAL AIRPORT
BATTLE CREEK, MICHIGAN

Electron Acceptor or Process	Expressed BTEX Assimilative Capacity (μg/L)
Dissolved Oxygen	1,800
Nitrate + Nitrite	260
Ferric Hydroxide	550
Sulfate	2,800
Methanogenesis	10,800
Expressed Assimilative Capacity	16,210
Highest Observed Total BTEX Concentration, August 1994	3,552

4-30

SECTION 5

GROUNDWATER MODEL

5.1 GENERAL OVERVIEW AND MODEL DESCRIPTION

In order to help estimate degradation rates for dissolved BTEX compounds at Site 3 and to help predict the future migration of these compounds, Parsons ES modeled the fate and transport of the dissolved BTEX plume. The modeling effort had three primary objectives: 1) to predict the future extent and concentration of the dissolved contaminant plume by modeling the combined effects of advection, dispersion, sorption, and biodegradation; 2) to assess the possible risk to potential downgradient receptors; and 3) to provide technical support for the natural attenuation remedial option at post-modeling regulatory negotiations. The model was developed using site-specific data and conservative assumptions about governing physical and chemical processes. Because of the conservative nature of model input, the reduction in contaminant mass caused by natural attenuation is expected to exceed model predictions. This analysis is not intended to represent a baseline assessment of potential risks posed by site contamination.

The Bioplume II code was used to estimate the potential for dissolved BTEX migration and degradation by natural processes at Site 3. The Bioplume II model incorporates advection, dispersion, sorption, and biodegradation to simulate contaminant plume migration and degradation. The model is based upon the USGS Method of Characteristics (MOC) two-dimensional (2-D) solute transport model of Konikow and Bredehoeft (1978). The model was modified by researchers at Rice University to include a biodegradation component that is activated by a superimposed DO plume. Based on the work of Borden and Bedient (1986), the model assumes a reaction between DO and BTEX that is instantaneous relative to the advective groundwater velocity. Bioplume II solves the USGS 2-D solute transport equation twice, once for hydrocarbon concentrations in the aquifer and once for a DO plume. The two plumes are combined using superposition at every particle move to simulate the instantaneous, biologically-mediated, reaction between hydrocarbons and oxygen.

In recent years it has become apparent that anaerobic processes such as nitrate reduction (denitrification), iron reduction, sulfate reduction, and methanogenesis can be important BTEX degradation mechanisms (Grbic'-Galic', 1990; Beller et al., 1992; Edwards et al., 1992; Edwards and Grbic'-Galic'; 1992; Grbic'-Galic' and Vogel, 1987; Lovely et al., 1989; Hutchins, 1991). Although there is evidence that anaerobic biodegradation of fuel hydrocarbons is occurring at Site 3, these processes were not accounted for during the modeling. Limiting the simulation to oxygen-limited degradation is a conservative assumption intended to prevent overestimation of

5-1

degradation rates. The following subsections discuss in more detail the model setup, input parameters and assumptions, model calibration, and simulation results.

5.2 CONCEPTUAL MODEL DESIGN AND ASSUMPTIONS

Prior to developing a groundwater model, it is important to determine if sufficient data are available to provide a reasonable estimate of aquifer conditions. In addition, it is important to ensure that any limiting assumptions can be justified. The most important assumption made when using the Bioplume II model is that oxygen-limited biodegradation is occurring at the site. The Bioplume II model assumes that the limiting factors for biodegradation are: 1) the presence of an indigenous hydrocarbon degrading microbial population, and 2) sufficient background electron acceptor (DO) concentrations. Data and information presented in Sections 3 and 4 suggest that oxygen, nitrate, ferric hydroxide, sulfate, and carbon dioxide (methanogenesis) are being used as electron acceptors for aerobic and anaerobic biodegradation. To be conservative, only oxygen was considered as an electron acceptor in the Bioplume II model presented herein. To model biodegradation of BTEX with DO as an electron acceptor, the isopleth maps for these compounds were superimposed on the model grid. Data from this map were then used for model input.

Based on the data presented in Section 3, the shallow saturated zone was conceptualized and modeled as a shallow unconfined aquifer consisting of fine to coarse sand with some gravel (Figures 3.3 and 3.4). The use of a 2-D model is appropriate at Site 3 because the saturated interval is relatively homogenous and water level data indicate that the local flow system, as defined by horizontal and vertical gradients, will likely prevent significant vertical migration of dissolved contamination.

Bioventing has been implemented in the area of greatest soil contamination (in the center of the fire training pit). Bioventing will further reduce the source of continuing dissolved BTEX contamination at the site. After calibration, one of the predictive contaminant fate and transport simulations assumed continued BTEX source reduction as a result of bioventing.

5.3 INITIAL MODEL SETUP

Where possible, the initial setup for this model was based on existing site data. Where site-specific data were not available, reasonable assumptions for the types of materials comprising the shallow saturated zone were made based on widely accepted literature values. The following sections describe the basic model setup. Those Bioplume II model parameters that were varied during model calibration are discussed in Section 5.4.

5.3.1 Grid Design and Boundary Conditions

The maximum grid size for the Bioplume II model is limited to 20 columns by 30 rows. The dimension of each column and row can range from 0.1 to 999.9 feet. A 20- by 20-cell grid was used to model the Site. Each grid cell was 90 feet long by 60 feet wide. The grid was oriented so that the longest dimension was parallel to the overall direction of groundwater flow. The model grid covers an area of 1.75 million square feet, or approximately 40 acres. The full extent of the model grid is indicated on Figure 5.1.
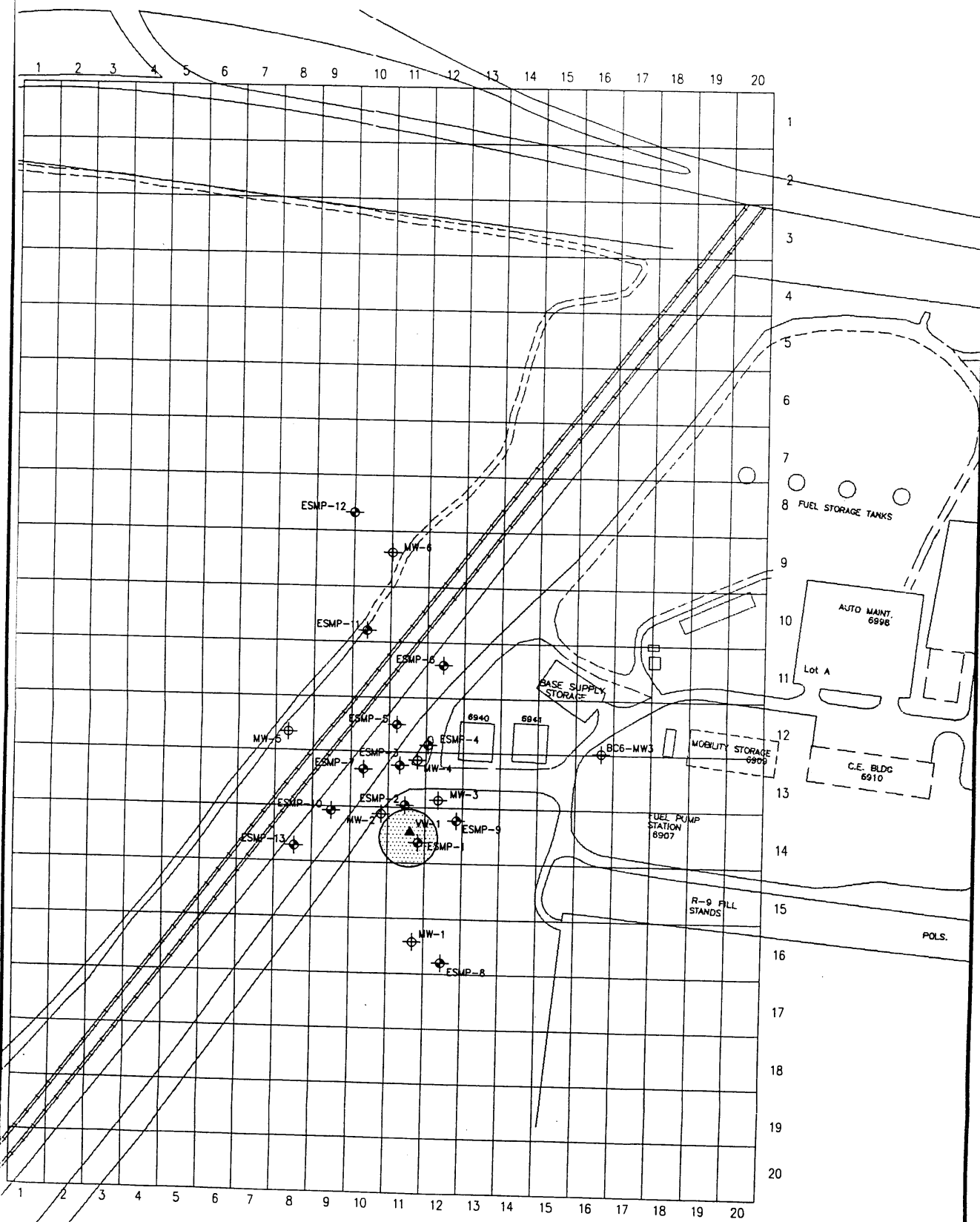
5-2

LEGEND

⊕ ESMP-1   MONITORING POINT

⊕ MW-1   MONITORING WELL

▲ VW-1   BIOVENTING VENT WELL

▓ FIRE TRAINING AREA

FIGURE 5.1

MODEL GRID

Site 3 (Fire Training Area)
Intrinsic Remediation TS
Michigan Air National Guard, W.K. Kellogg Airport
Battle Creek, Michigan

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Denver, Colorado

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Model boundaries are mathematical statements that represent hydrogeologic boundaries, such as areas of specified head (e.g., surface water bodies or contour lines of constant hydraulic head) or specified flux. Hydrogeologic boundaries are represented by three mathematical statements that describe the hydraulic head at the model boundaries. These include:

- Specified-head boundaries (Dirichlet condition) for which the head is determined as a function of location and time only. Surface water bodies exhibit constant head conditions. Specified-head boundaries are expressed mathematically as:

$$Head = f(x, y, z, t)$$

Where: f is the function symbol,

x, y, and z are position coordinates, and

t is time.

- Specified-flow boundaries (Neumann conditions) for which the mathematical description of the flux across the boundary is given. The flux is defined as a volumetric flow rate per unit area (e.g., $ft^3/ft^2/day$). No-flow boundaries are a special type of specified-flow boundary and are set by specifying the flux to be zero. Examples of no-flow boundaries include groundwater divides and impermeable hydrostratigraphic units. Specific flux boundaries are expressed mathematically as:

$$Flux = f(x, y, z, t)$$

- Head-dependent flow boundaries (Cauchy or mixed-boundary conditions) where the flux across the boundary is calculated from a given boundary head value. This type of flow boundary is sometimes referred to as a mixed-boundary condition because it is a combination of a specified-head boundary and a specified-flow boundary. Head-dependent flow boundaries are used to model leakage across semipermeable boundaries. Head dependent flow boundaries are expressed mathematically as (Bear, 1979):

$$Flux = \frac{(H_0 - H)K'}{B'}$$

Where: H = Head in the zone being modeled (generally the zone containing the contaminant plume)

H_0 = Head in external zone (separated from plume by semipermeable layer)

K' = Hydraulic conductivity of semipermeable layer

B' = Thickness of semipermeable layer

5-4

Natural hydraulic boundaries are modeled using a combination of the three types of model boundary conditions listed above. When possible, hydrologic boundaries such as surface water bodies, groundwater divides, contour lines, or hydrologic barriers should coincide with the perimeter of the model. In areas lacking obvious hydrologic boundaries, specified-head or specified-flux boundaries can be specified at the model perimeter if the boundaries are far enough removed from the contaminant plume that transport calculations are not affected. Bioplume II requires the entire model domain to be bounded by zero-flux cells (also known as no-flow cells), with other boundary conditions established within the subdomain specified by the no-flow cells.

Specified-head boundaries for the model were set on the northern, northwestern, and southern perimeters of the model grid to simulate the north-northwestward flow of groundwater observed at the site. The head of the southern boundary was estimated to be 891.7 to 893.25 feet msl. The northern model boundary was defined by projection of the water table and the observed hydraulic gradient. The constant-head cells along the northern and northeastern boundaries were estimated to be from 888.3 to 888.75 feet msl. These constant-head cells were placed far enough away from the BTEX plume to avoid potential boundary interferences.

The eastern and much of the western model boundaries were left as no-flow boundaries. In this case, the flux through these boundaries is assumed to be zero because flow is parallel to these boundaries. The base or lower boundary of the model is also assumed to be no-flow. The upper model boundary is defined by the simulated water table surface.

5.3.2 Groundwater Elevation and Gradient

The water table elevation map presented in Figure 3.5 was used to define the starting heads input into the Bioplume II model. Groundwater flow in the vicinity of Site 3 is to the north-northwest with an average gradient of approximately 0.003 ft/ft. Localized gradients to the west are as high as 0.007 ft/ft. No data are available to quantify seasonal variations in groundwater flow direction or gradient at the site; it was assumed that the observed water levels were representative of steady-state conditions. As described in Section 5.4.1, the model was calibrated to the observed water table.

5.3.3 BTEX Concentrations

The total dissolved BTEX concentrations obtained from laboratory analytical data for each CPT and well location were used for model development. At CPT nests, the highest BTEX concentration from all monitoring points at that location was used as the representative concentration. Table 4.3 presents dissolved BTEX concentration data. Figures 4.2 and 4.3 show the spatial distribution of dissolved BTEX compounds in August 1994.

The observed BTEX plume covers an area of approximately 140,000 square feet (3 acres). The shape and distribution of the total BTEX plume is the result of advective-dispersive transport and biodegradation of dissolved BTEX contamination. As described

in Section 5.4.2, the simulated BTEX plume was calibrated to match the observed BTEX plume.

5.3.4 Dissolved Oxygen

As discussed previously, the Bioplume II model assumes an instantaneous reaction between the BTEX plume and the DO plume. The discussion presented in Section 4 suggests that DO, nitrate, ferric iron, sulfate, and carbon dioxide (methanogenesis) are being used as electron acceptors for biodegradation of BTEX compounds at Site 3. To be conservative, the total BTEX plume at Site 3 was modeled assuming that DO was the only electron acceptor being utilized for the biodegradation of the BTEX compounds.

Groundwater samples collected in uncontaminated portions of the aquifer suggest that background DO concentrations at the site are as high as 6.87 mg/L. To be conservative, background oxygen levels were assumed to be 5.0 mg/L for Bioplume II model development. Table 4.4 contains DO data for the site. Figures 4.4 and 4.5 are DO isopleth maps.

The upgradient constant-head cells in the Bioplume II model require background electron acceptor concentrations to be input as constant concentrations to simulate incoming electron acceptors. A DO concentration of 5.0 mg/L was used for these cells.

5.4 MODEL CALIBRATION

Model calibration is an important component in the development of any numerical groundwater model. Calibration of the flow model demonstrates that the model is capable of matching hydraulic conditions observed at the site; calibration of a contaminant transport model superimposed upon the calibrated flow model helps verify that contaminant loading and transport conditions are being appropriately simulated. The numerical flow model presented herein was calibrated by altering transmissivity in a trial-and-error fashion until simulated heads approximated observed field values within a prescribed accuracy. After calibration of the flow model, the numerical transport model was calibrated by altering hydraulic parameters, transport parameters, and stresses (i.e., injection wells and their contaminant loading rates) in a trial-and-error fashion until the simulated BTEX plume approximated observed field values. Table 5.1 lists input parameters used for the modeling effort. Model input and output are included in Appendices C and D, respectively.

5.4.1 Water Table Calibration

The shallow water table at Site 3 was assumed to be influenced only by continuous recharge and discharge at the constant-head cells established at the upgradient and downgradient model boundaries. Recharge of the aquifer through rainfall or by other sources was not included in the model because of a lack of reliable data. Only the initial water levels at the constant-head cells and the transmissivity were varied to calibrate the water table surface. The model was calibrated under steady-state conditions.

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TABLE 5.1
BIOPLUME II MODEL INPUT PARAMETERS
SITE 3 (FIRE TRAINING AREA) INTRINSIC REMEDIATION TS
MICHIGAN AIR NATIONAL GUARD
W.K. KELLOGG MEMORIAL AIRPORT
BATTLE CREEK, MICHIGAN

Parameter	Description	Calibrated Model Setup	Models Site 3 NSR	BCSR
NTIM	Maximum number of time steps in a pumping period	8	67	39
NPMP	Number of Pumping Periods	1	1	4
NX	Number of nodes in the X direction	20	20	20
NY	Number of nodes in the Y direction	20	20	20
NPMAX	Maximum number of Particles NPMAX=(NX-2)(NY-2)(NPTPND) + (Ns*)(NPTPND) + 250	3750	3750	3750
NPNT	Time step interval for printing data	1	1	1
NITP	Number of iteration parameters	7	7	7
NUMOBS	Number of observation points	0	0	0
ITMAX	Maximum allowable number of iterations in ADIP [b]	100	100	100
NREC	Number of pumping or injection wells	3	3	3
NPTPND	Initial number of particles per node	9	9	9
NCODES	Number of node identification codes	2	2	2
NPNTMV	Particle movement interval (IMOV)	0	0	0
NPNTVL	Option for printing computed velocities	2	2	2
NPNTD	Option to print computed dispersion equation coefficients	2	0	0
NPDELC	Option to print computed changes in concentration	0	0	0
NPNCHV	Option to punch velocity data	0	0	0
NREACT	Option for biodegradation, retardation and decay	1	1	1
PINT	Pumping period (years)	17	67	17,1,1,20
TOL	Convergence criteria in ADIP	0.001	0.001	0.001
POROS	Effective porosity	0.25	0.25	0.25
BETA	Characteristic length (long. dispersivity; feet)	16	16	16
S	Storage Coefficient	0 (Steady-State)	0	0
TIMX	Time increment multiplier for transient flow	-	-	-
TINIT	Size of initial time step (seconds)	-	-	-
XDEL	Width of finite difference cell in the x direction (feet)	60	60	60
YDEL	Width of finite difference cell in the y direction (feet)	90	90	90
DLTRAT	Ratio of transverse to longitudinal dispersivity	0.1	0.1	0.1
CELDIS	Maximum cell distance per particle move	0.5	0.5	0.5
ANFCTR	Ratio of Tyy to Txx (1 = isotropic)	1	1	1
DK	Distribution coefficient	0.023	0.023	0.023
RHOB	Bulk density of the solid (grams/cubic centimeter)	1.6	1.6	1.6
THALF	Half-life of the solute	-	-	-
DEC1	Anaerobic decay coefficient	0	0	0
DEC2	Reaeration coefficient (day^{-1})	0.0009	0.0009	0.0009
F	Stoichiometric Ratio of HC to Oxygen	3.1	3.1	3.1

[*] Ns = Number Of Nodes That Represent Fluid Sources (Wells or Constant Head Cells)

[b] ADIP = Alternating-Direction Implicit Procedure (subroutine for solving ground water flow equation)

Hydraulic conductivity is an important aquifer characteristic that determines the ability of the water-bearing strata to transmit groundwater. Transmissivity is the product of the hydraulic conductivity and the thickness of the aquifer. An accurate estimate of hydraulic conductivity is important to help quantify advective groundwater flow velocities and to define the flushing potential of the aquifer and the quantity of electron-acceptor-charged groundwater that is entering the site from upgradient locations. Based on the work of Rifai *et al.* (1988), the Bioplume II model is particularly sensitive to variations in hydraulic conductivity. Lower values of hydraulic conductivity result in a slower-moving plume that degrades at a slower rate because less oxygen, nitrate, iron, sulfate, and carbon dioxide are available for biodegradation. Higher values of hydraulic conductivity result in a faster moving plume that degrades faster because more electron acceptors are available for biodegradation.

Saturated thickness data from previous reports, CPT logs, and water level measurements were used in conjunction with the average hydraulic conductivity as determined from slug tests (0.0114 ft/min) to estimate an initial uniform transmissivity for the entire model domain. Based on slug tests performed at the site, hydraulic conductivity varies from 6×10^{-3} ft/min to 4.03×10^{-2} ft/min and is within the accepted range for sandy materials (Freeze and Cherry, 1979). To better match heads in the model to observed values, the transmissivities were progressively varied in blocks and rows until the simulated water levels for cells corresponding to the selected well locations matched the observed water levels as closely as possible. Figure 5.2 shows the calibrated water table. Calibrated model hydraulic conductivities ranged from 6.0×10^{-4} ft/min to 3.6×10^{-2} ft/min (1.0×10^{-5} feet per second (ft/sec) to 6.0×10^{-4} ft/sec).

Water level elevation data from nine monitoring well and monitoring point locations were used to compare measured and simulated heads for calibration. The nine selected locations were: ESMP-1, ESMP-2, ESMP-3, ESMP-5, ESMP-6, ESMP-7, ESMP-12, MW-1, and MW-6.

The root mean squared (RMS) error is commonly used to express the average difference between simulated and measured heads. RMS error is the average of the squared differences between measured and simulated heads, and can be expressed as:

$$RMS = \left[\frac{1}{n} \sum_{i=1}^{n} (h_m - h_s)_i^2 \right]^{0.5}$$

Where:

n = the number of points where heads are being compared

h_m = measured head value

h_s = simulated head value.

The RMS error between observed and calibrated values at the nine comparison points was 0.16 foot, which corresponds to a calibration error of 3.13 percent (water levels dropped 5 feet over the length of the model grid). RMS error calculations are summarized in Appendix C. A plot of measured vs. calibrated heads shows a random distribution of points and is also shown in Appendix C. Deviation of points from a

5-8

LEGEND

⊕ ESMP-1   MONITORING POINT

⊕ MW-1   MONITORING WELL

▲ VW-1   BIOVENTING VENT WELL
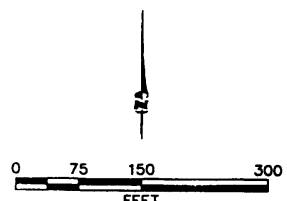
▨ FIRE TRAINING AREA

FIGURE 5.2

CALIBRATED WATER TABLE

Site 3 (Fire Training Area)
Intrinsic Remediation TS
Michigan Air National Guard, W.K. Kellogg Airport
Battle Creek, Michigan

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Denver, Colorado

0   75   150   300
FEET

straight line should be randomly distributed in a plot of results from computer simulations (Anderson and Woessner, 1992).

In solving the groundwater flow equation, Bioplume II establishes the water table surface and calculates an overall hydraulic balance that accounts for the numerical difference between flux into and out of the system. The hydraulic mass balance for the calibrated model was excellent, with 99.98 percent of the water flux into and out of the system being numerically accounted for (i.e., a 0.02-percent error). According to Anderson and Woessner (1992), a mass balance error of around 1 percent is acceptable, while Konikow (1978) indicates an error of less than 0.1 percent is ideal.

5.4.2 BTEX Plume Calibration

Model input parameters affecting the distribution and concentration of the simulated BTEX plume were modified so that model predictions matched dissolved total BTEX concentrations observed in August 1994. To do this, model runs were made using the calibrated steady-state hydraulic parameters coupled with the introduction of contaminants. For this site, the calibration also involved a time element, because it is known that contaminants were released from 1977 through 1986. As a result, the plume calibration simulations were made with a time constraint of 17 years; in other words, computed BTEX plume concentrations and configurations were compared to August 1994 data after 17 years of simulation time incorporating the introduction of contaminants into the groundwater.

Because residual-phase contamination is present in the vicinity of the water table at the site, it was necessary to include injection wells to simulate partitioning of BTEX compounds from the residual phase into the groundwater. The location of the injection wells is shown on Figure 5.3. Locations of injection wells were based on the extent of soil contamination as indicated on Figure 4.1, the extent of groundwater contamination indicated on Figure 4.2, and the location of the fire training pit.

While the term "injection well" suggests contaminants are being introduced at a point, Bioplume II assumes that contamination introduced at a well instantly equilibrates throughout the entire cell in which the well is located. The injection rate for the cells was set at 1×10^{-5} ft^3/sec, a value low enough so that the flow calibration and water balance were not affected. Relatively high BTEX concentrations were injected in upgradient injection wells because of the low pumping rate and the influx of oxygen introduced at the upgradient constant head cells. Replenishment of oxygen quickly degraded BTEX concentrations at the head of the plume, which in turn required larger injection concentrations of BTEX to produce observed BTEX contours. On the basis of assumptions outlined in Section 5.3.4, it was assumed that the initial DO concentration in the shallow aquifer was uniformly 5.0 mg/L, and that water with that DO concentration would be continually introduced at the southern grid boundary.

Total BTEX injection concentrations were determined by varying the injection concentration for the various wells from 25 to 1,500 mg/L until the modeled total BTEX plume approximated the total BTEX plume observed in August 1994. By varying the injection well concentrations, the coefficient of retardation, dispersivity, and the reaeration coefficient, the BTEX plume was calibrated to the existing plume in terms of

5-10

LEGEND

⊕ ESMP-1   MONITORING POINT

⊕ MW-1   MONITORING WELL

▲ VW-1   BIOVENTING VENT WELL

● INJECTION WELL FOR
  BIOPLUME II SIMULATION

▦ FIRE TRAINING AREA

FIGURE 5.3

LOCATION OF
SIMULATED INJECTION
WELLS

Site 3 (Fire Training Area)
Intrinsic Remediation TS
Michigan Air National Guard, W.K. Kellogg Airport
Battle Creek, Michigan

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Denver, Colorado

0   75   150   300
FEET

LEGEND

⊕ ESMP-1   MONITORING POINT

⊕ MW-1   MONITORING WELL

▲ VW-1   BIOVENTING VENT WELL

●   INJECTION WELL FOR
BIOPLUME II SIMULATION

▒   FIRE TRAINING AREA

⌐50⌐   LINE OF EQUAL SIMULATED BTEX
CONCENTRATION (μg/L)

0   75   150   300
FEET

FIGURE 5.4

CALIBRATED BTEX PLUME

Site 3 (Fire Training Area)
Intrinsic Remediation TS
Michigan Air National Guard, W.K. Kellogg Airport
Battle Creek, Michigan

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Denver, Colorado

migration distance and BTEX concentrations in the source area. The calibrated plume configuration is shown on Figure 5.4.

The extent of the calibrated model plume, while not identical to the observed BTEX plume, compares favorably. The highest measured BTEX concentration (3,552 µg/L at the vent well) is simulated in the calibrated model at 3,105 µg/L. Several of the contour intervals plotted from the calibrated model (10-, 50-, and 1,000-µg/L) delineate areas more extensive than indicated by the observed concentrations. This is an unavoidable result of the injection concentrations necessary to simulate the extent of the observed BTEX plume and illustrates one of the limitations of Bioplume II to accurately characterize actual physical site conditions. In particular, the model allows only the application of a constant reaeration coefficient over the extent of the modeled area. Simulations with lower BTEX input concentrations resulted in a more restricted plume extent. Similarly, higher reaeration coefficients resulted in restriction of plume migration. The application of localized variations in the reaeration coefficient would allow more detailed reproduction of the extent of the plume while decreasing the concentrations in the interior of the plume. The computed plume is useful, however, in that it conservatively approximates the observed distribution of BTEX. Although resulting concentrations exceed measured concentrations, it will provide a more conservative estimate of plume migration.

5.4.2.1 Discussion of Parameters Varied During Plume Calibration

As noted previously, the transport parameters varied during plume calibration were effective porosity, dispersivity, the coefficient of retardation, and the coefficient of reaeration. These parameters were varied with the intent of limiting plume migration to the observed extents. While these parameters were varied with this common intent, each had a slightly different impact on the size and shape of the simulated plume.

BTEX concentrations in the simulated injection wells were also varied, but these parameters had little effect on plume size and shape unless they were too low to permit the plume to migrate beyond the source cells or so high that the simulated concentrations were unrealistic.

5.4.2.1.1 Effective Porosity

Effective porosity plays a significant role in calculations of groundwater velocity, which will in turn affect the simulation of contaminant transport. As noted in Section 3.3.3.3, the effective porosity of the aquifer materials at Site 3 was assumed to be 25 percent. This value was not changed during calibration.

5.4.2.1.2 Dispersivity

Much controversy surrounds the concepts of dispersion and dispersivity. Longitudinal dispersivity values for sediments similar to those found at the site range from 0.1 to 200 feet (Walton, 1988). Longitudinal dispersivity was originally estimated as 16 feet, using one-tenth of the distance between the spill source and the longitudinal centroid of the plume. Dispersivity estimation calculations are included in Appendix C. Transverse dispersivity values generally are estimated as one-tenth (0.1) of the longitudinal

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dispersivity values (Domenico and Schwartz, 1990). The initial model input assumed the same ratio.

During plume calibration, the initial estimate of 16 feet for the longitudinal dispersivity was found to be the most suitable for reproducing the BTEX plume extent. In addition, the original estimate of the ratio of transverse dispersivity to longitudinal dispersivity of 0.1 was found to be the most appropriate.

5.4.2.1.3 Coefficient of Retardation

Retardation of the BTEX compounds relative to the advective velocity of the groundwater occurs when BTEX molecules are sorbed to the aquifer matrix. The coefficients of retardation for the BTEX compounds were calculated based on measured TOC concentrations in uncontaminated portions of the shallow saturated zone. An assumed bulk density of 1.6 grams/cubic centimeter (Freeze and Cherry, 1979) and published values of the soil sorption coefficient (K_{oc}) for the BTEX compounds (as listed in Wiedemeier et al., 1994) were used in lieu of site-specific data. The results of these calculations are summarized in Table 5.2. To be conservative, the range of coefficients of retardation calculated for benzene (1.15 to 1.5) was used as a constraint for model input . The coefficient of retardation originally input to the model was 1.5. The lower the assumed coefficient of retardation, the farther the BTEX plume will migrate downgradient.

During plume calibration, the coefficient of retardation was gradually decreased from the initial value of 1.5 to a value of 1.15. This variable was decreased to allow the BTEX plume to migrate a sufficient distance down-gradient from the source cells. In addition, decreasing the value of this parameter also resulted in decreasing the BTEX concentrations near the source area by increasing the travel rate of the contaminants.

5.4.2.1.4 Reaeration Coefficient

The reaeration coefficient is a first-order rate constant used by Bioplume II to simulate the replenishment of oxygen into the groundwater by soil-gas diffusion and rainwater infiltration. A reaeration coefficient of 0.003 day^{-1} was originally estimated, based on other documented Bioplume modeling efforts (see, for example, Rifai et al., 1988).

The reaeration coefficient had a significant effect on limiting plume migration and total BTEX concentration. At its originally estimated value of 0.003 day^{-1}, the plume did not extend more than one cell length beyond the source cells, and the highest computed concentrations was 1,120 µg/L. This coefficient was reduced to 0.0009 day^{-1}, and the calculated plume extent was more realistic, with computed concentrations closer to observed concentrations in the source area.

5.5 SENSITIVITY ANALYSIS

The purpose of the sensitivity analysis is to determine the effect of varying model input parameters on model output. Based on the work of Rifai et al. (1988), the Bioplume II model is most sensitive to changes in the coefficient of reaeration, the coefficient of anaerobic decay, and the hydraulic conductivity (transmissivity) of the

TABLE 5.2

CALCULATION OF RETARDATION COEFFICIENTS
SITE 3 (FIRE TRAINING AREA) INTRINSIC REMEDIATION TS
MICHIGAN AIR NATIONAL GUARD
W.K. KELLOGG MEMORIAL AIRPORT
BATTLE CREEK, MICHIGAN

Compound	K_{oc} (L/Kg) [a]	Maximum Fraction Organic Carbon [b]	Minimum Fraction Organic Carbon [b]	Average Fraction Organic Carbon [b]	Distribution Coefficient, K_d (L/Kg) Maximum[c1]	Minimum[c2]	Average[c3]	Bulk Density (Kg/L) [d]	Effective Porosity [d]	Coefficient of Retardation Maximum	Minimum	Average
Benzene	79	0.00098	0.00029	0.00069	0.077	0.023	0.055	1.60	0.25	1.50	1.15	1.35
Toluene	190	0.00098	0.00029	0.00069	0.186	0.055	0.132	1.60	0.25	2.19	1.35	1.84
Ethylbenzene	468	0.00098	0.00029	0.00069	0.459	0.136	0.324	1.60	0.25	3.94	1.87	3.08
m-Xylene	405	0.00098	0.00029	0.00069	0.397	0.117	0.281	1.60	0.25	3.54	1.75	2.80
o-Xylene	422	0.00098	0.00029	0.00069	0.414	0.122	0.292	1.60	0.25	3.65	1.78	2.87
p-Xylene	357	0.00098	0.00029	0.00069	0.350	0.104	0.247	1.60	0.25	3.24	1.66	2.58

[a] From technical protocol (Wiedemeier *et al.*, 1994)

[b] From site data

[c1] K_d = Maximum Fraction Organic Carbon x K_{oc}

[c2] K_d = Minimum Fraction Organic Carbon x K_{oc}

[c3] K_d = Average Fraction Organic Carbon x K_{oc}

[d] Literature values

media, and is less sensitive to changes in the retardation factor, porosity, and dispersivity. The coefficient of anaerobic decay was set to zero and the lowest calculated retardation factor was used in the calibrated model. Therefore, the sensitivity analysis was conducted by varying transmissivity, dispersivity, and the coefficient of reaeration.

To perform the sensitivity analyses, individual runs of the plume calibration model were made with the same input as the calibrated model, except that one of the aforementioned parameters was varied. The models were run for 17 years, just as the original, so that the independent effect of each variable could be assessed. As a result, six sensitivity runs of the calibrated model were made, with the following variations:

1) Transmissivity uniformly increased by a factor of 5;

2) Transmissivity uniformly decreased by a factor of 5;

3) Longitudinal dispersivity increased by a factor of 2;

4) Longitudinal dispersivity decreased by a factor of 5;

5) Reaeration coefficient increased by a factor of 5; and

6) Reaeration coefficient decreased by a factor of 5.

The results of the sensitivity analyses are shown graphically in Figures 5.5, 5.6, and 5.7. These figures display the modeled BTEX concentrations versus distance along the centerline of the plume (in the tenth model column). This manner of displaying data is useful because BTEX concentrations are highest in the tenth column, the plume is relatively narrow, and the plume migrates in a direction generally parallel to the model grid. Furthermore, the figures allow easy visualization of the changes in BTEX concentration caused by varying model input parameters.

The effects of varying transmissivity are shown by Figure 5.5. Uniformly increasing the transmissivity by a factor of five resulted in complete biodegradation of the plume at the same rate at which the contaminant was introduced into the system. This results from the greater flux of water through the model area bringing a greater mass of DO into contact with the plume. Because more oxygen is present, biodegradation occurs more rapidly. Also, the faster groundwater velocity produced by the higher transmissivity initially results in greater spreading of the plume, further exposing the BTEX to oxygenated water. In contrast, decreasing the transmissivity by a factor of five slowed overall plume migration, which in turn caused an increase in measured BTEX levels in the source area and downgradient of the source area. Increased BTEX concentrations in the source area are caused by a reduction in the amount of oxygen being brought into contact with the plume from upgradient locations. Decreasing transmissivity also resulted in a slightly shorter plume.

The effects of varying dispersivity are illustrated by Figure 5.6. Both longitudinal and transverse dispersivity were varied for this analysis, as the ratio of the two values was kept constant at 0.1. Increasing the dispersivity by a factor of two resulted in slightly lower maximum BTEX concentrations and an apparent decrease in plume length.

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Concentration Distribution for Various Values of Transmissivity (T)

Legend:
— Calibrated T
······ Calibrated T x 5
—·— Calibrated T x 0.2

Y-axis: Total BTEX Concentration (µg/l)

X-axis: Distance Along Centerline of Plume (feet)
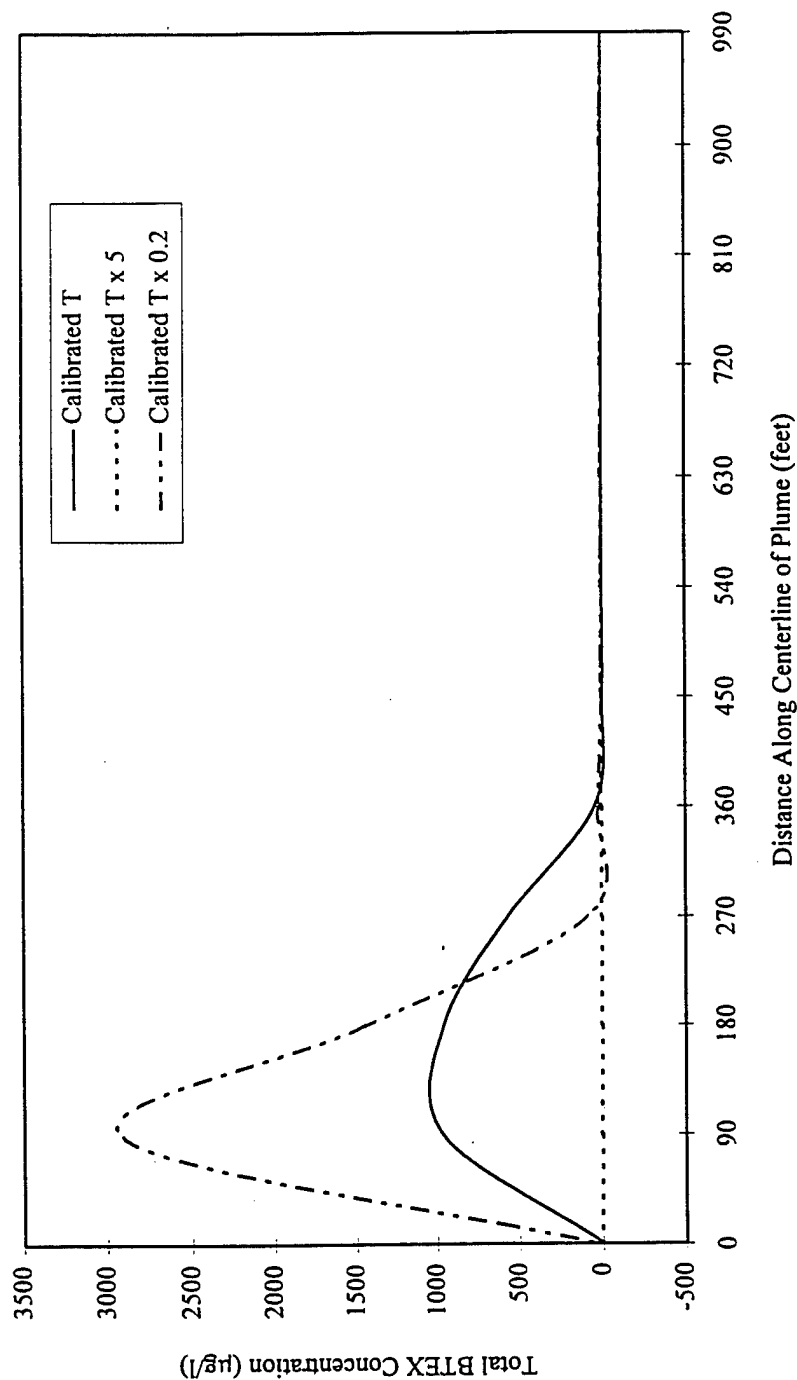
FIGURE 5.5

MODEL SENSITIVITY TO
VARIATIONS IN TRANSMISSIVITY

Site 3 (Fire Training Area)
Intrinsic Remediation TS
Michigan Air National Guard, W.K. Kellogg Airport
Battle Creek, Michigan

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Denver, Colorado

M:\45010\DRAWINGS\95DN0119, 2/27/95 at 13:00

Concentration Distribution for Various Values of Longitudinal Dispersivity (BETA)

Total BTEX Concentration (μg/L)

Distance Along Centerline of Plume (feet)

Legend:
— Calibrated BETA
······ Calibrated BETA x 2
—·— Calibrated BETA x 0.2

M:\45010\DRAWINGS\95DN0119. 2/27/95 at 13:00

Concentration Distribution for Various Values of Reaeration Coefficient

Legend:
— Calibrated Value
····· Calibrated Value x 5
–··– Calibrated Value x 0.2

X-axis: Distance Along Centerline of Plume (feet)
Y-axis: Total BTEX Concentration (µg/L)
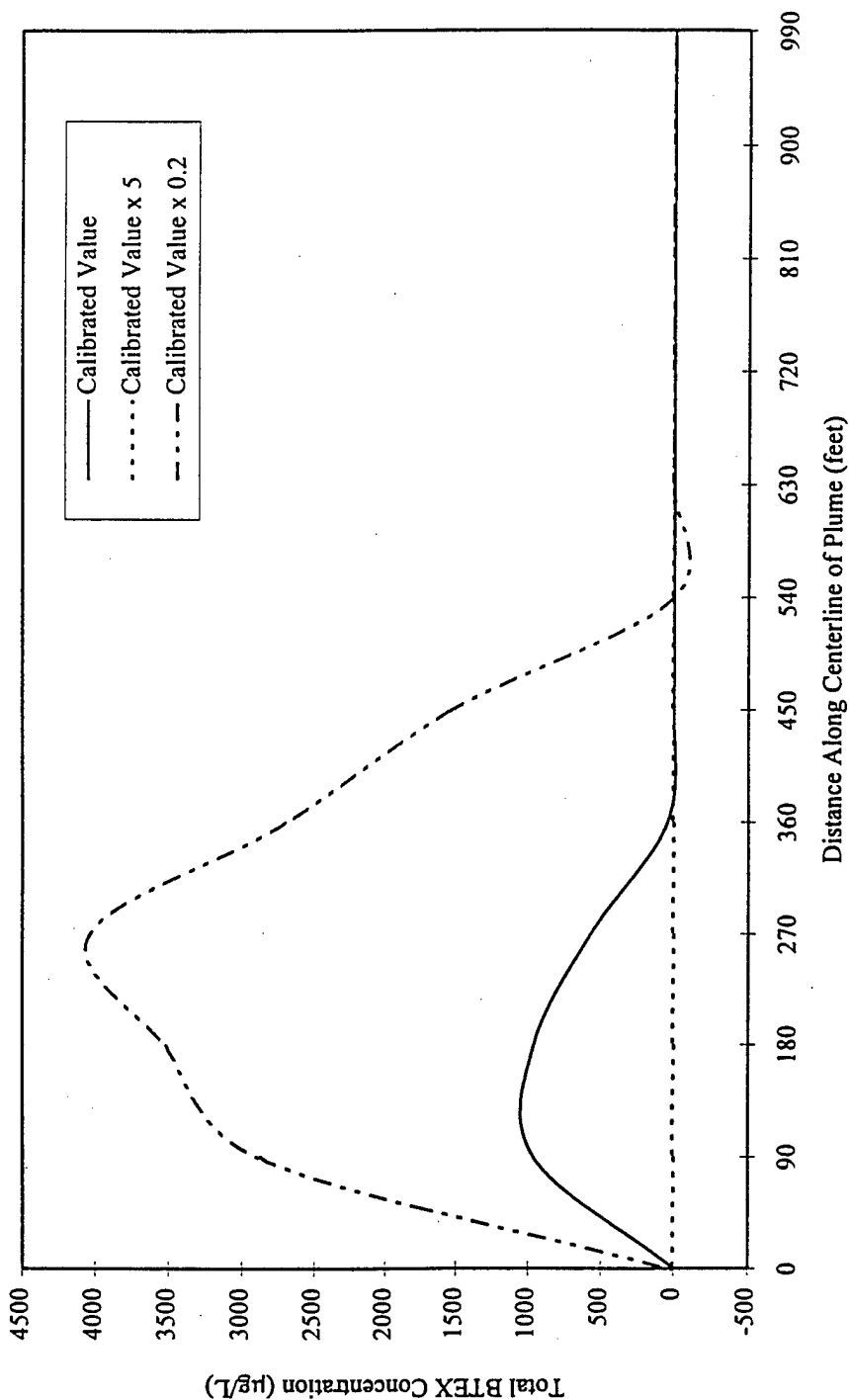
FIGURE 5.7

MODEL SENSITIVITY TO VARIATIONS IN REAERATION

Site 3 (Fire Training Area)
Intrinsic Remediation TS
Michigan Air National Guard, W.K. Kellogg Airport
Battle Creek, Michigan

PARSONS ENGINEERING SCIENCE, INC.

Denver, Colorado

M:\45010\DRAWINGS\95DN0119, 2/27/95 at 13:00

Decreasing dispersivity by a factor of five produced a slightly longer plume with higher BTEX concentrations. The apparent anomaly of the lower dispersivity value creating a shorter plume and the higher dispersivity value creating a longer plume is due to the influence of the westerly component of groundwater flow.

Figure 5.7 shows the effects of varying the coefficient of reaeration. Increasing this parameter by a factor of five results complete biodegradation of the BTEX plume, similar to the results obtained by increasing the transmissivity. This is a result of increased oxygen available for biodegradation. Conversely, decreasing the coefficient of reaeration by a factor of five decreases the amount of oxygen available for biodegradation, increasing the length of the plume by approximately 200 feet and increasing the computed maximum BTEX concentrations to approximately 4,000 µg/L.

The results of the sensitivity analysis suggest that the calibrated model used for this report is reasonable. The calibrated model is most sensitive to transmissivity and the reaeration coefficient. Increasing the coefficient of reaeration or the transmissivity greatly diminishes the predicted BTEX concentration and distribution. Lowering the values of these two variables lengthens the plume to beyond reasonable distances based on current observations at the site. The model appears to be relatively insensitive to dispersivity.

5.6 MODEL RESULTS

To predict fate and transport of dissolved BTEX compounds at Site 3, two Bioplume II simulations were run under steady-state conditions. The first simulation assumed no source removal, with contaminant loading continuing at the rates which produced the calibrated model. The second simulation incorporated source reduction over 3 years, ultimately resulting in only 10 percent of the original source loading. This was done to estimate the impact of the bioventing unit which is currently in place in the center of the fire training pit source area. Complete input and output files are presented in Appendices C and D. Model results are described in the following sections.

5.6.1 No Source Removal (Model NSR)

Model NSR was used to simulate the migration and biodegradation of the BTEX plume assuming no source reduction or removal. In other words, the loading rates at the injection wells used to produce the calibrated BTEX plume were not reduced. Contamination was therefore continually introduced at a constant rate. This simulation was run for 50 years beyond the original calibrated model ending time, for a total simulation time of 67 years. Figure 5.8 shows the extent of the BTEX plume after 14 years of prediction time. Following the 14-year time step, the model suggests complete degradation of the BTEX plume as the rate of oxygen supplied to the system accelerates the rate of natural attenuation resulting in apparent instantaneous contaminant destruction. This illustrates one of the limitations of Bioplume II. With a constant source, the plume would probably persist at reduced concentrations in the source area but due to the limitations imposed by the cell sizing required to discretize the area of interest, the total number of cells available for discretization, and the uniformity of oxygen influx, the BTEX introduced into the source cells is instantaneously degraded during the simulation.
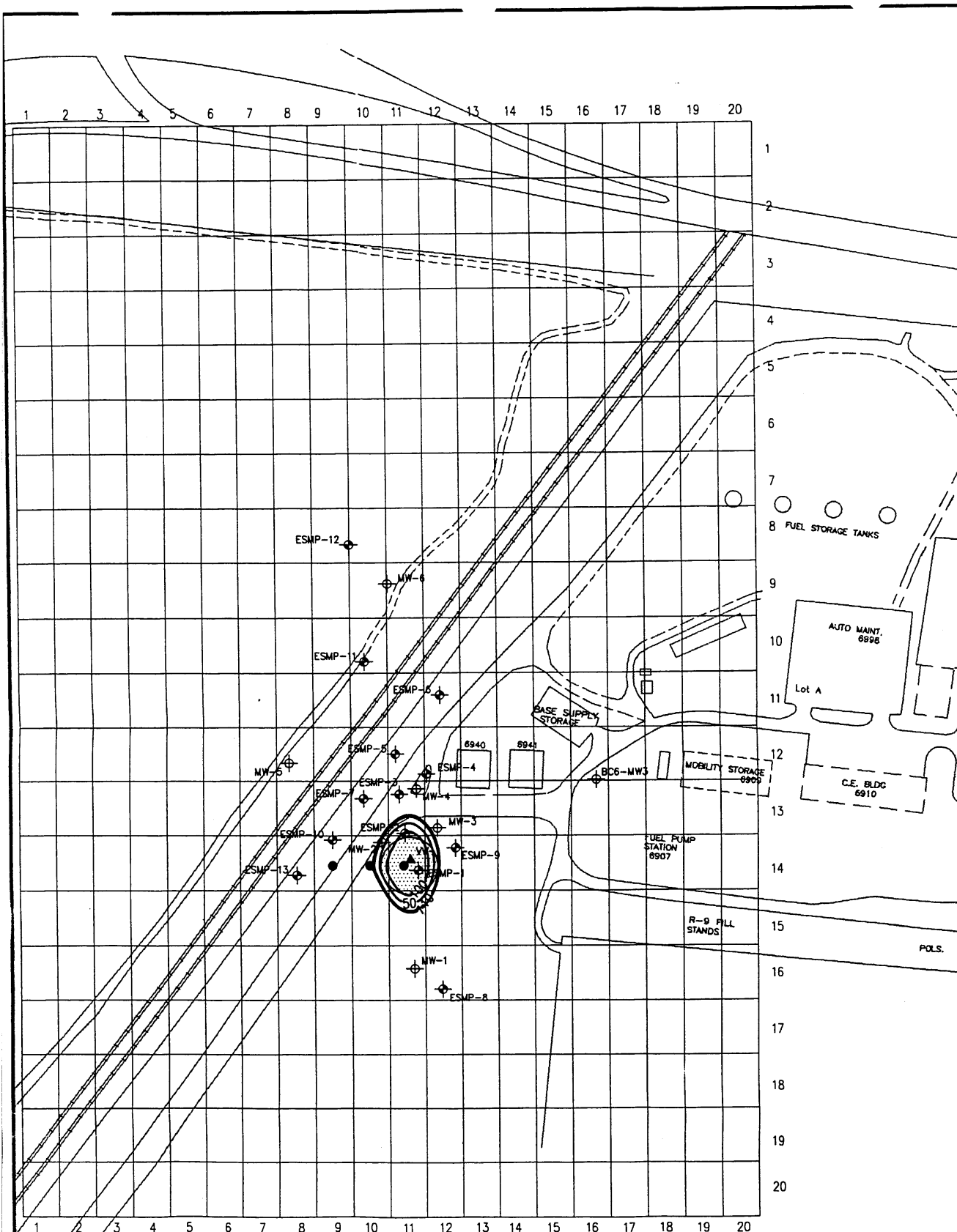
5-20

LEGEND

⊕ ESMP-1   MONITORING POINT

⊕ MW-1   MONITORING WELL

▲ VW-1   BIOVENTING VENT WELL

● INJECTION WELL FOR
   BIOPLUME II SIMULATION

▦ FIRE TRAINING AREA

0   75   150   300
FEET

FIGURE 5.8

MODEL NSR
SIMULATED BTEX PLUME
AFTER 14 YEARS

Site 3 (Fire Training Area)
Intrinsic Remediation TS
Michigan Air National Guard, W.K. Kellogg Airport
Battle Creek, Michigan

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The measured dissolved BTEX concentrations at Site 3 are relatively low and did not require very high source concentrations to reproduce the plume. The BTEX concentrations currently being introduced into the modeled area are probably less than in the past and less than those required to produce the observed plume. This is a result of source reduction due to natural weathering, which would be expected to continue through time. Within the first year of the prediction simulation, a downgradient portion of the plume separates from the central core of the plume approximately 300 feet downgradient from the source cells. The concentrations in the separate, downgradient lobe of the plume ranged from 1 to 22 μg/L. Within the plume centered around the source cells, concentrations ranged from 221 μg/L at the leading edge to 3,364 μg/L in the source cells.

By the fifth year of the prediction period, the detached plume was completely degraded and the leading edge of the core plume did not extend more than 250 feet beyond the source cells (Figure 5.9). Concentrations ranged from 465 μg/L near the leading edge of the plume to 2,872 μg/L in the source cells. This plume geometry remained relatively stable from year 5 through year 12 of the simulation, with some fluctuation of the upgradient extent of the plume and with a general decrease in simulated BTEX concentrations in all cells. The upgradient fluctuation is probably a result of upgradient migration due to dispersion away from the source area.

The plume extent decreased further by the thirteenth year of simulation with concentrations ranging from 14 μg/L at the leading edge to 2,117 μg/L at the source cells. In simulation year 14, the plume consisted of a single cell with a BTEX concentration of 287 μg/L. Years 15 to 50 were characterized by instantaneous biodegradation of the BTEX entering the source cells due to the continuous influx of oxygenated water into the modeled area resulting in no computed BTEX plume.

Of note in the simulation was the spontaneous generation of BTEX concentrations in several cells unrelated to the source cells and not in the path of plume migration. This occurred in two cells along the upgradient constant head boundary and resulted in downgradient migration of the generated BTEX along columns 13 and 16 of the model grid. This indicates that there is probably a mathematical instability in the finite difference solution of this problem. However, the results of this simulation are still useful, indicating that with continuous BTEX loading, the plume is likely to be confined to the immediate source area as the influx of oxygen from upgradient and from reaeration will enable the microorganisms present to metabolize the hydrocarbons at a rate equal to their introduction into the system.

Representing the source area as constant overestimates contaminant input into the system. Total soil BTEX concentrations in the capillary fringe from borehole ESSB-6 at 27 to 27.5 feet bgs were reported as 4,983 μg/kg. To determine the total contribution that the residual BTEX could make to dissolved concentrations, it was assumed that this sample is representative of contamination in the capillary fringe over the entire source area; that the capillary fringe and smear zone due to water table fluctuation is three feet above the water table; and that instantaneous flushing and dissolution of the residual BTEX would occur. Such a scenario could potentially produce a concentration of 30,785 μg/L of total BTEX in the groundwater. Because instantaneous flushing and dissolution would probably not occur, and based on the maximum observed groundwater

LEGEND

ESMP-1 ⊕ ES MONITORING POINTS

MW-1 ⊕ EXISTING MONITORING WELLS

VW-1 ▲ BIOVENTING VENT WELL

● INJECTION WELL FOR
  BIOPLUME II SIMULATION

▦ FIRE TRAINING ARES

0   75   150   300
|————|————|—————————|
            FEET

FIGURE 5.9

MODEL NSR
SIMULATED BTEX PLUME
AFTER 5 YEARS

Site 3 (Fire Training Area)
Intrinsic Remediation RAP
Michigan Air National Guard,
W.K. Kellogg Airport
Battle Creek, Michigan

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Denver, Colorado

concentration of 3,552 µg/L at the vent well, the calculated residual source represents a leaching potential for approximately 8 years (30,785 µg/L/3,552 µg/L) to create the observed maximum BTEX concentration. In addition, the residual hydrocarbons would weather and degrade in the source area, thus further decreasing the loading rates. Thus, the residual soil contamination does not appear to contain sufficient BTEX concentrations to contribute to the groundwater through leaching for more than 8 years. Calculations on which this evaluation are based are presented in Appendix C.

5.6.2 Source Removal via Bioventing (Model BCSR)

As discussed in Section 1.2, a pilot-scale bioventing system was installed in the center of the fire training pit in September 1992 and is currently in operation. In soil gas samples collected during system installation, TVH concentrations in the source area ranged from 88 to 29,000 ppmv. Benzene concentrations ranged from 0.057 to 120 ppmv, while toluene, ethylbenzene, and total xylenes concentrations ranged from not detected (at a detection limit of 0.01 ppmv) to 50 ppmv (ES, 1992).

Bioventing is an *in situ* process where low-flow air injection is used to enhance the biodegradation of organic contaminants in subsurface soils by supplying oxygen to indigenous microbes. The pilot-scale system began operating in September 1992. The influx of oxygen provided by air injection stimulated microbial degradation of hydrocarbons in the unsaturated zone. The bioventing system is injecting air (with approximately 21 percent oxygen) at relatively low flow rates to stimulate additional biodegradation of the fuel residuals. Bioventing also increases the diffusion of oxygen into the water table promoting increased biodegradation of dissolved BTEX (Barr, 1993). In addition, soil near and below the water table will be oxygenated by water table fluctuation. Testing during installation of the venting well indicated that the bioventing system is capable of increasing soil gas oxygen concentrations at least 50 feet in all directions from the well.

During initial testing of the bioventing system, results indicated that the system was capable of degrading up to 3,683 mg of fuel per kg of soil each year. Soil samples were collected during bioventing system installation, and the total recoverable petroleum hydrocarbon concentrations ranged from 120 to 15,000 mg/kg (ES, 1992). These results suggest that after 5 years, nearly all of the residual fuel in soil within the effective radius of the pilot venting well should be degraded, or equilibrium concentrations should be reached.

Site soil gas data indicate that since the system began operating in September 1992, soil gas hydrocarbon concentrations have decreased significantly. A sample of soil gas from the bioventing well collected in October 1993 contained 1.5 ppmv of TVH. In addition, BTEX compounds were reported as below the detection limit of 0.002 ppmv (ES, unpublished data). Comparison of these data to the data collected during system installation indicates a significant decrease in soil gas TVH and BTEX concentrations.

The maximum total BTEX concentration detected in soil during the bioventing system installation was a concentration of 32.8 mg/kg from the vent well at a depth of 8 feet bgs. The effectiveness of the bioventing system is supported by the soil BTEX results from the field activities of August 1994. BTEX compounds were detected in samples from

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only two soil boreholes, ESSB-5 and ESSB-6, both within the bermed Fire Training Area. In ESSB-6, BTEX concentrations range from 0.109 mg/kg at a depth of 4 to 4.5 feet bgs to 4.98 mg/kg at a depth of 27 to 27.5 feet bgs. This suggests that the bioventing is most effective at removing the volatile compounds from the shallower soil zone and less effective in the capillary fringe where soil moisture restricts oxygen delivery.

Evaluation of bioventing results at 16 other sites (including sites with conditions similar to those at Site 3) shows that after 1 year of operation, average BTEX concentrations in soil were reduced by 91 percent (for benzene) to greater than 99 percent (for ethylbenzene and xylenes) (ES, 1994b). During the same time frame, average soil TPH concentrations were reduced by 70 percent, confirming that the BTEX compounds are preferentially removed.

Given the record of bioventing performance and the site-specific soil gas sampling results, it appears that soil BTEX concentrations have been significantly reduced and will continue to be reduced while the pilot-scale bioventing system is in operation. Based on this information, a predictive model was set up to reflect source removal using bioventing technology. As a starting assumption, model BCSR assumed that in 1 year of bioventing system operation, 50 percent of the original soil BTEX concentration was removed. In the second year of operation, the model set-up assumed that an additional 25 percent of the original BTEX was removed. In the third and all subsequent years of operation, it was assumed that steady-state conditions were reached, with 10 percent of the original BTEX concentration remaining.

To simulate the reduction in BTEX concentrations, it was assumed that reductions in soil concentrations produced similar reductions in the BTEX loading rates. For example, for the first predictive year of the BCSR simulation (year 18 of the total simulation), the loading rates at each injection well were reduced to 50 percent of the calibrated model rates. In the second predictive year the loading rates were decreased to 25 percent of the original rates, and in the third and all subsequent years the loading rates were left at 10 percent of the original rates. While the absence of confirmatory soil samples makes it difficult to quantify the actual decrease in loading rates that will be brought about by bioventing, these modeling assumptions can provide an indication of the potential effects of source reduction.

Model results for this case suggest that within 7 years after source reduction begins, the dissolved BTEX compounds will not be present in groundwater at the site. Reduction of the source results in rapid biodegradation of the remaining concentrations of hydrocarbons, because the lower loading rates do not introduce BTEX into the aquifer at a rate exceeding the rates of biodegradation and sorption. Figures 5.10, 5.11, and 5.12 show the results of this model after 2, 3, and 5 years of source reduction, respectively.

After 2 years (Figure 5.10), the plume consists of two separate elements, with the smaller downgradient element having a maximum concentration of 13 μg/L and the plume in the area of the source cells having a maximum concentration of 1,941 μg/L. The predicted total plume area at this time is smaller than observed in 1994. After 3 years (Figure 5.11), the central portion of the plume is similar to the plume predicted after 2 years, but total BTEX concentrations decrease to approximately 1,000 μg/L. BTEX concentrations in the separate downgradient portion of the plume are further reduced to
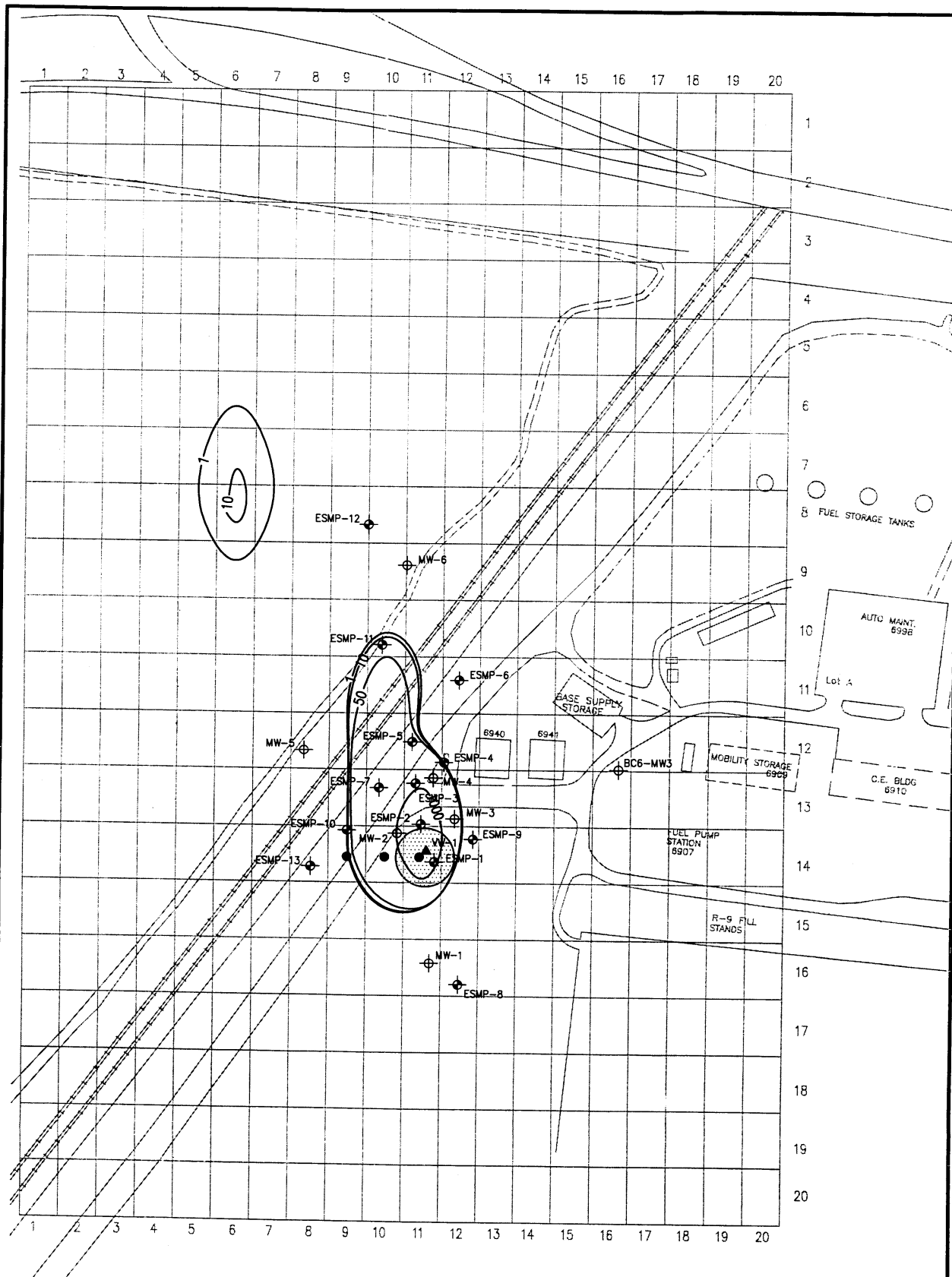
LEGEND

ESMP-1 ⊕ ES MONITORING POINTS

MW-1 ⊕ EXISTING MONITORING WELLS

VW-1 ▲ BIOVENTING VENT WELL

● INJECTION WELL FOR
BIOPLUME II SIMULATION

▦ FIRE TRAINING ARES
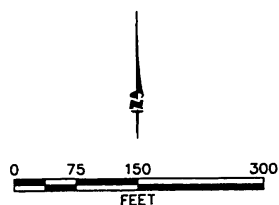
0   75   150   300
FEET
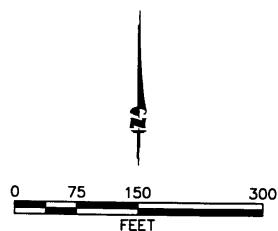
FIGURE 5.10

MODEL BCSR
SIMULATED BTEX PLUME
AFTER 2 YEARS

Site 3 (Fire Training Area)
Intrinsic Remediation RAP
Michigan Air National Guard,
W.K. Kellogg Airport
Battle Creek, Michigan
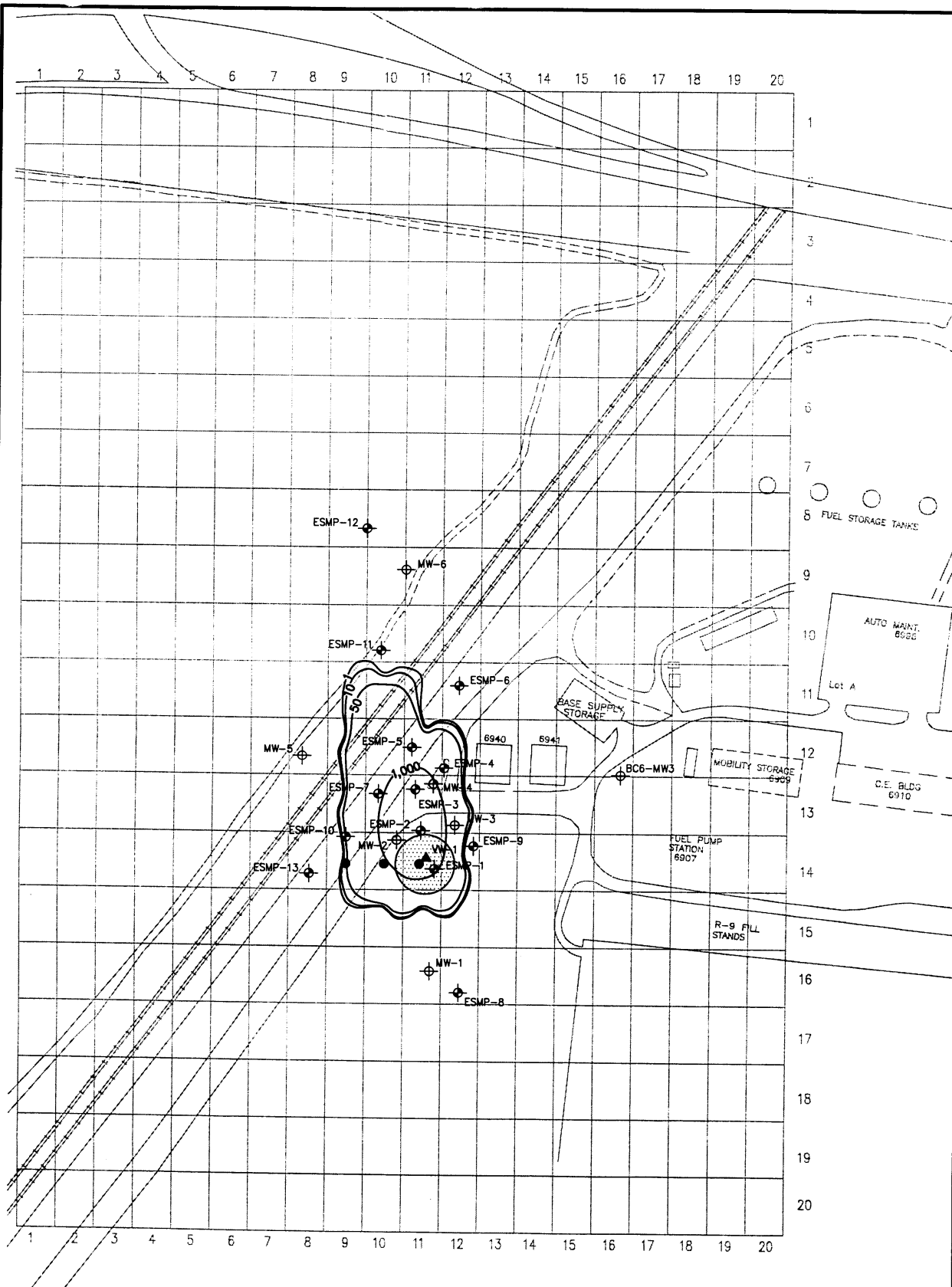
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LEGEND

ESMP-1 ⊕ ES MONITORING POINTS

MW-1 ⊕ EXISTING MONITORING WELLS

VW-1 ▲ BIOVENTING VENT WELL

● INJECTION WELL FOR
BIOPLUME II SIMULATION

▢ FIRE TRAINING ARES

0   75   150   300
FEET

FIGURE 5.11

**MODEL BCSR
SIMULATED BTEX PLUME
AFTER 3 YEARS**

Site 3 (Fire Training Area)
Intrinsic Remediation RAP
Michigan Air National Guard,
W.K. Kellogg Airport
Battle Creek, Michigan

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Denver, Colorado

LEGEND

ESMP-1 — ⬦ ES MONITORING POINTS

MW-1 — ⬦ EXISTING MONITORING WELLS

VW-1 — ▲ BIOVENTING VENT WELL

● INJECTION WELL FOR BIOPLUME II SIMULATION

▨ FIRE TRAINING ARES
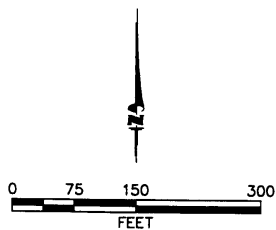
0   75   150   300
FEET
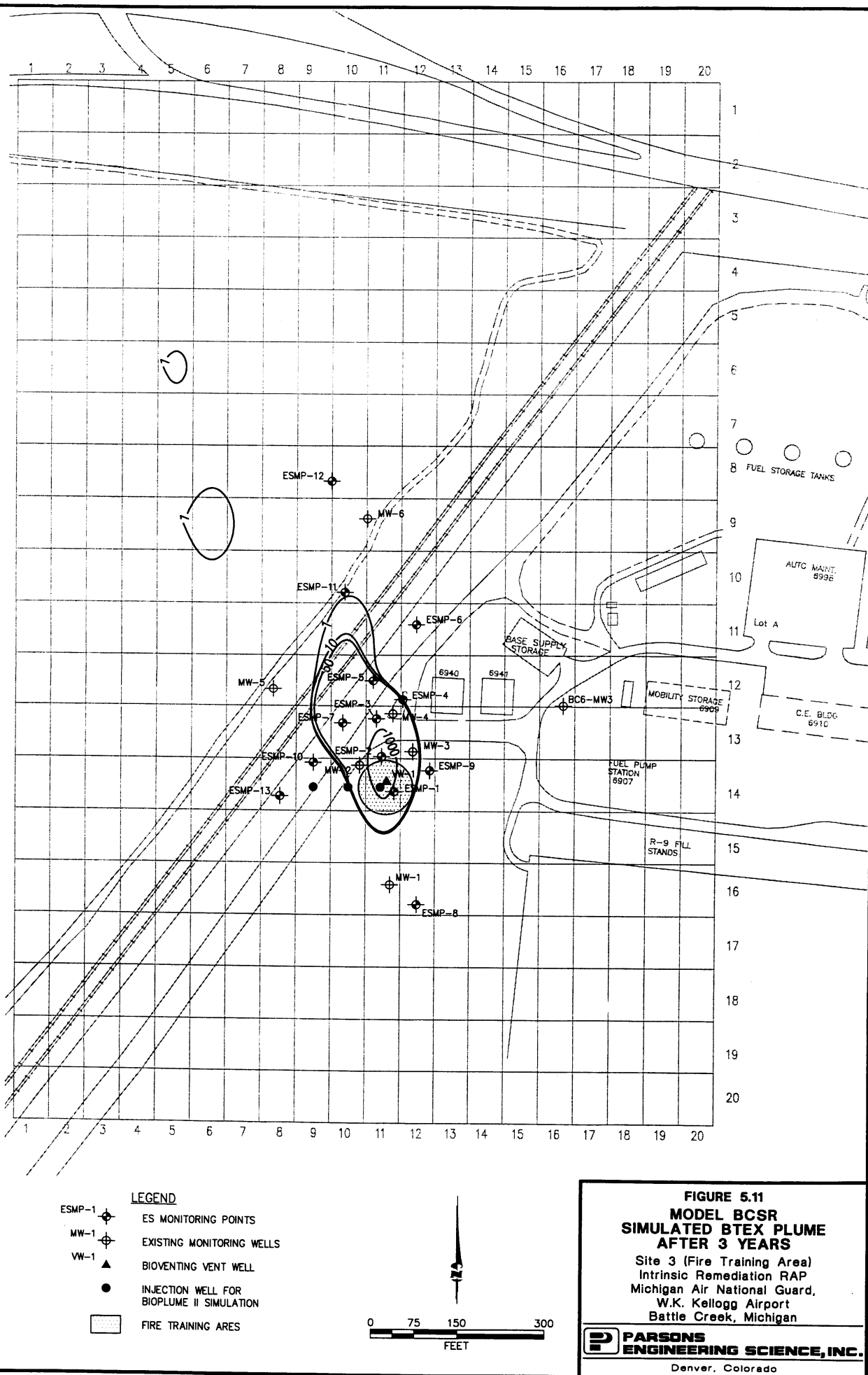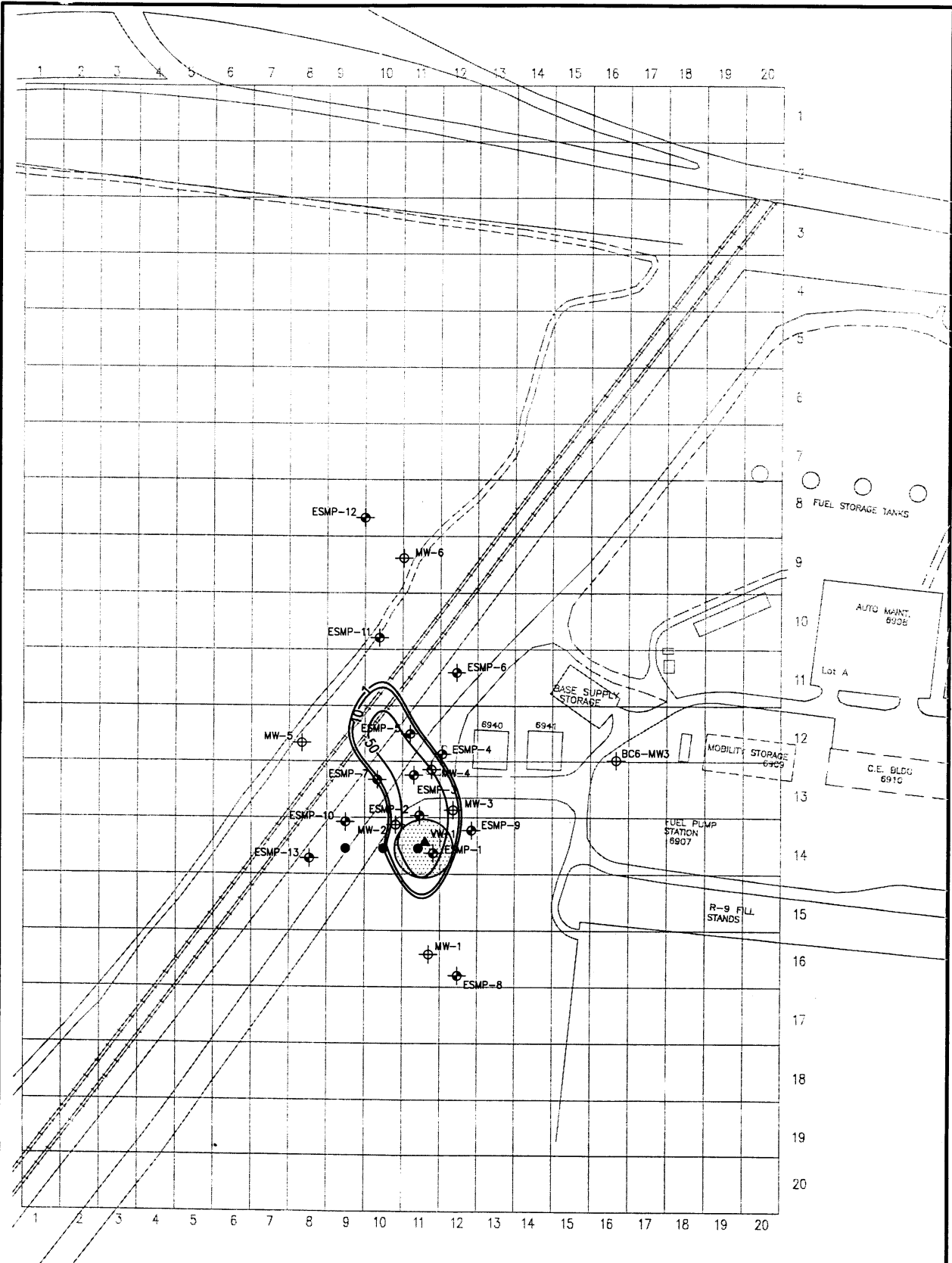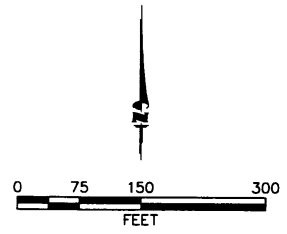
FIGURE 5.12

MODEL BCSR
SIMULATED BTEX PLUME
AFTER 5 YEARS

Site 3 (Fire Training Area)
Intrinsic Remediation RAP
Michigan Air National Guard,
W.K. Kellogg Airport
Battle Creek, Michigan

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1.5 and 4 µg/L in two downgradient cells. Five years after source reduction is initiated, the model predicts that the plume front extends approximately 200 feet beyond the source cells (Figure 5.12), with a maximum calculated concentration of 131 µg/L in the source cell. At this time, the separate, downgradient plume has been completely degraded. Seven years after source reduction begins, the remaining dissolved BTEX plume is completely degraded.

5.7 CONCLUSIONS AND DISCUSSION

The results of two different Bioplume II model scenarios at Site 3 indicate that dissolved BTEX contamination is not likely to extend beyond the present observed extent and will likely be significantly biodegraded within 15 years. The first scenario, model NSR, assumed that BTEX loading rates in the source area would remain constant (at the rates used to calibrate the BTEX plume) for the full duration of the simulation. The second scenario, model BCSR, assumed that BTEX loading rates would be reduced via bioventing in the source area. NSR results suggest that the dissolved BTEX plume has reached its maximum extent and that after 15 years, BTEX compounds will be completely degraded. BCSR results suggest that after source reduction, the areal distribution of BTEX compounds will not exceed the 1994 plume limits and that the BTEX will be completely degraded within 7 years.

Model results imply that as a worst-case scenario, BTEX compounds would migrate approximately 720 feet downgradient from the source area. Taking into account the model cell size and the resolution of concentrations at the margin of the plume, it appears unlikely that detectable concentrations of BTEX will reach any potential receptors more than 750 feet downgradient from the site.

In both cases, model simulations are very conservative for several reasons, including:

1. Aerobic respiration, denitrification, iron reduction, sulfate reduction, and methanogenesis are all occurring at this site; however, only DO is considered as an electron acceptor during model simulations;

2. The stoichiometry used to determine the ratio between DO and total BTEX assumed that no microbial cell mass was produced during the reaction. As discussed in Section 4.3.2.1, this approach may be too conservative by a factor of three.

3. The highest DO concentration observed at the site was 6.67 mg/L. The highest DO concentration assumed during model simulations was 5.0 mg/L.

4. A low coefficient of retardation for benzene (1.15) was used for model simulations. Coefficient of retardation values for the other BTEX compounds range from 1.35 to 3.94. The use of the low coefficient of retardation tends to increase the distance traveled by the simulated BTEX plume, but provides a more accurate estimate of benzene transport.

5. The calibrated BTEX plume was slightly larger than the plume delineated by field data, although concentrations in the source area were similar.

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Source reduction through bioventing, in concert with natural attenuation, can greatly impact the persistence of the BTEX contamination observed at the site. Comparing the results of the NSR model with the results of the BCSR simulation shows the effects of source reduction, which allows for more rapid and thorough degradation of the BTEX compounds. The rapid degradation of BTEX observed in simulation BCSR is feasible, given the observed DO concentrations, the maximum observed BTEX concentrations, and the conservative assumptions made in constructing the simulation. Bioventing is currently underway, and appears to have significantly reduced residual soil BTEX concentrations. Geochemical evidence also strongly suggests that anaerobic biodegradation is occurring in the central portions of the plume, which would further increase the rates of hydrocarbon attenuation.

Models NSR and BCSR represent two endpoints in a continuum of probable scenarios at Site 3. NSR represents the "worst case" in that it assumes BTEX dissolution into the aquifer will continue at the same rate indefinitely, while BTEX loading rates should actually decrease as the residual product weathers and the continuing dissolution removes more and more of those compounds. Model BCSR is a more realistic prediction that assumes removal of BTEX from the soil via bioventing will result in a proportional decrease in BTEX partitioning into the dissolved phase. It is likely that future site conditions will fall somewhere between these endpoints, with the plume not extending as far as indicated by NSR, but with BTEX in the source area persisting longer than predicted by BCSR.

SECTION 6

COMPARATIVE ANALYSIS OF REMEDIAL ALTERNATIVES

This section presents the development and comparative analysis of two groundwater remedial alternatives for Site 3 at the Michigan Air National Guard facility at W. K. Kellogg Memorial Airport, Battle Creek, Michigan. The intent of this evaluation is to determine whether intrinsic remediation is an appropriate and cost-effective remedial technology to consider when developing final remedial strategies for Site 3, especially when combined with other innovative and conventional remedial technologies.

Section 6.1 presents the evaluation criteria be used to evaluate groundwater remedial alternatives. Section 6.2 discusses the development of remedial alternatives considered part of this demonstration project. Section 6.3 provides a brief description of each of these remedial alternatives. Section 6.4 provides a more detailed analysis of the remedial alternatives using the defined remedial alternative evaluation criteria. The results of this evaluation process are summarized in section 6.5.

6.1 REMEDIAL ALTERNATIVE EVALUATION CRITERIA

The evaluation criteria used to identify which remedial alternative may be most appropriate for shallow groundwater contamination at Site 3 were adapted from those recommended by the USEPA (1988) for selecting remedies for Superfund sites (OSWER Directive 9355.3-01). These criteria included (1) long-term effectiveness and permanence, (2) technical and administrative implementability, and (3) relative cost. The following sections briefly describe the scope and purpose of each evaluation criterion. This report focuses on the potential use of intrinsic remediation and source reduction technologies to reduce BTEX concentrations within the shallow groundwater to levels which meet regulatory standards intended to be protective of human health or the environment.

6.1.1 Long-Term Effectiveness and Permanence

Each remedial technology or remedial alternative (which can be a combination of remedial technologies such as intrinsic remediation and institutional controls) was analyzed to determine how effectively it will minimize groundwater plume expansion so that groundwater quality standards can be achieved at a downgradient point of compliance (POC). The expected technical effectiveness based on case histories from other sites with similar conditions is also evaluated. The ability to minimize potential impacts to surrounding facilities and operations is considered. Also, the ability of each remedial alternative to protect both current and potential future receptors from potential exposure to site-related contamination in shallow groundwater is qualitatively assessed

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by conservatively estimating if a potential exposure pathway involving groundwater could be completed, either now or in the future. This evaluation criterion also included permanence and the ability to reduce contaminant mass, toxicity, and volume. Time to implementation and time until protection is achieved are described. Long-term reliability for providing continued protection, including an assessment of potential for failure of the technology and the potential threats resulting from such a failure, is also evaluated.

6.1.2 Implementability

The technical implementation of each remedial technology or remedial alternative was evaluated in terms of technical feasibility and availability. Potential shortcomings and difficulties in construction, operations, and monitoring are presented and weighed against perceived benefits. Requirements for any post-implementation site control such as LTM and land use restrictions are described. Details on administrative feasibility in terms of the likelihood of public acceptance and the ability to obtain necessary approvals are discussed.

6.1.3 Cost

The total cost (present worth) of each remedial alternative was estimated for relative comparison. An estimate of capital costs, and operations and post-implementation costs for site monitoring and controls is included. An annual inflation factor of 5 percent was assumed in present worth calculations. Costs were estimated based on vendor quotes, and historic system monitoring, operation, and maintenance costs.

6.2 FACTORS INFLUENCING ALTERNATIVES DEVELOPMENT

Several factors were considered during the identification and screening of remedial technologies for addressing shallow groundwater contamination at Site 3. Factors considered included the objectives of the natural attenuation demonstration program, contaminant, groundwater and soil properties, present and future land use, and potential exposure pathways. The following section briefly describes each of these factors and how they were used to narrow the list of potentially applicable remedial technologies to the final remedial alternatives considered for Site 3.

6.2.1 Program Objectives

The intent of the Natural Attenuation (Intrinsic Remediation) Demonstration Program sponsored by AFCEE is to develop a systematic process for scientifically investigating and documenting naturally occurring subsurface attenuation processes that can be factored into overall site remediation plans. The objective of this program and the specific Site 3 study is to provide solid evidence of intrinsic remediation of dissolved fuel hydrocarbon so that this information can be used to develop an effective groundwater remediation strategy. A secondary goal of this multi-site initiative is to provide a series of regional case studies which demonstrate that natural processes of contaminant degradation can often reduce contaminant concentrations in groundwater to below acceptable cleanup standards before completion of potential exposure pathways.

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Because the objective of this program is to study natural processes of the saturated zone rather than all contaminated media (soil, soil gas, etc.), technologies have been evaluated based on their potential impact on shallow groundwater and phreatic soils. Technologies that can reduce vadose zone contamination and partitioning of contaminants into groundwater have also been evaluated. Many of the source removal technologies evaluated in this section will also reduce soil and soil gas contamination, but it is important to emphasize that the remedial alternatives developed in this document are not intended to remediate all contaminated media. Additional program objectives set forth by AFCEE include cost-effectiveness and minimization of waste. Technologies that may meet these criteria include institutional controls, soil vapor extraction, bioventing, biosparging, groundwater pump and treat, and intrinsic remediation. Soil excavation, slurry walls, sheet piling, carbon adsorption, *ex situ* biological or chemical treatment, and on-site/off-site disposal are not attractive technology candidates for this site.

6.2.2 Contaminant Properties

The site-related contaminants considered as part of this demonstration at Site 3 are the BTEX compounds. The source of this contamination is a mixture of waste JP-4 jet fuel, waste oils, waste hydraulic fluid, and spent cleaning solvents present as residual contamination in capillary fringe and saturated soil within the source area of Site 3. The physiochemical characteristics of both JP-4 and the individual BTEX compounds will greatly influence the effectiveness and selection of a remedial technology.

Petroleum hydrocarbon mixtures, such as JP-4 jet fuel, are comprised of over 300 compounds with different physiochemical characteristics. JP-4 is classified as a LNAPL with a liquid density of approximately 0.75 grams per milliliter (g/ml) at 20°C. Many compounds within JP-4 sorb very well to soil and are concentrated in the capillary fringe because the mixture is less dense than water. JP-4 is slightly soluble in water with a maximum solubility of approximately 300 mg/L. JP-4 is also a primary substrate for biological metabolism. Simultaneous biodegradation of aliphatic, aromatic, and alicyclic hydrocarbons has been observed. In fact, mineralization rates of hydrocarbons in mixtures, such as JP-4, may be faster than mineralization of the individual constituents as a result of co-metabolic pathways (Jamison *et al.*, 1976; Perry, 1984).

Fuel oils are also classified as LNAPLs with a liquid density range of 0.81 to 0.95 g/ml at 20°C. They are slower to biodegrade than lighter hydrocarbons and are less mobile due to higher sorptive properties, lower volatility, and lower aqueous solubility (the solubility of fuel oil in water is 5 mg/L at 20°C).

The BTEX compounds are generally volatile, highly soluble in water, and adsorb less strongly to soil. These characteristics allow the BTEX compounds to leach more rapidly from contaminated soil into groundwater and migrate as dissolved contamination (Lyman *et al.*, 1992). All of the BTEX compounds are highly amenable to *in situ* degradation by both biotic and abiotic mechanisms.

Benzene is very volatile with a vapor pressure of 76 millimeters of mercury (mm Hg) at 20°C and a Henry's Law Constant of approximately 0.0054 atmosphere-cubic meter per mole (atm-m^3/mol) at 25°C (Hine and Mookerjee, 1975; Jury *et al.*, 1984). The solubility of benzene in water at 20°C has been reported to be 1,780 mg/L (Verschueren,

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1983). Benzene is normally biodegraded to carbon dioxide with catechol as a short-lived intermediate (Hopper, 1978; Ribbons and Eaton, 1992).

Toluene is also volatile with a vapor pressure of 22 mm Hg at 20°C and a Henry's Law Constant of about 0.0067 atm-m^3/mol at 25°C (Pankow and Rosen, 1988; Hine and Mookerjee, 1975). Toluene sorbs more readily to soil media relative to benzene, but still is still very mobile. The solubility of toluene in water at 20°C is approximately 515 mg/L at 20°C (Verschueren, 1983). Toluene has been shown to degrade to pyruvate, caetaldehyde, and completely to carbon dioxide via the intermediate catechol (Hopper, 1978; Wilson et al., 1986; Ribbons and Eaton, 1992).

Ethylbenzene has a vapor pressure of 7 mm Hg at 20°C and has a Henry's Law Constant of 0.0066 atm-m^3/mol (Pankow and Rosen, 1988; Valsaraj, 1988). Ethylbenzene sorbs more strongly to soils than benzene but less strongly than toluene (Abdul et al., 1987). Ethylbenzene is also less soluble than benzene and toluene in water, with a solubility of 152 mg/L at 20°C (Verschueren, 1983; Miller et al., 1985). Ethylbenzene ultimately degrades to carbon dioxide via its intermediate 3-ethylcatechol (Hopper, 1978; Ribbons and Eaton, 1992).

The three isomers of xylene have vapor pressures ranging from 7 to 9 mm Hg at 20°C and Henry's Law Constants of between 0.005 and 0.007 atm-m^3/mol at 25°C (Mackay and Wolkoff, 1973; Hine and Mookerjee, 1975; Pankow and Rosen, 1988). Of all of the BTEX compounds, xylenes sorb most strongly to soil, but still can leach from soil into the groundwater (Abdul et al., 1987). Xylenes have water solubilities of 152 to 160 mg/L at 20°C (Bohon and Claussen, 1951; Mackay and Shiu, 1981; Isnard and Lambert, 1988). Xylenes can degrade to carbon dioxide via pyruvate carbonyl intermediates (Hopper, 1978; Ribbons and Eaton, 1992).

Based on these physiochemical characteristics, intrinsic remediation, soil vapor extraction, bioventing, biosparging, groundwater extraction, and air stripping technologies could all be effective at destroying, collecting, and treating BTEX contaminants at Site 3.

6.2.3 Site-Specific Conditions

Two general categories of site-specific characteristics were considered when identifying remedial technologies for comparative evaluation as part of this demonstration project. The first category includes physical characteristics such as groundwater depth, gradient, flow direction, and soil type, which influence the types of remedial technologies most appropriate for the site. The second category involved assumptions about future land use and potential exposure pathways. Each of these site-specific characteristics have influenced the selection of remedial alternatives included in the comparative evaluation.

6.2.3.1 Groundwater and Soil Characteristics

Site geology and hydrogeology will have a profound effect on the transport of contaminants and the effectiveness and scope of required remedial technologies at a given site. Hydraulic conductivity is perhaps the most important aquifer parameter governing

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groundwater flow and contaminant transport in the subsurface. The velocity of the groundwater and dissolved contamination is directly related to the hydraulic conductivity of the saturated zone. Rising head slug tests completed at Site 3 indicate a relatively high conductivity within the vicinity of the source area and dissolved plume. Estimated hydraulic conductivity values ranged from 6.0×10^{-3} to 2.0×10^{-2} ft/min. These relatively high values are characteristic of sandy materials (see Sections 4 and 5 of this report). The high hydraulic conductivity of this site directly influences the fate and transport of contaminants. The shallow groundwater plume has migrated rapidly, increasing the areal extent of contamination (i.e., the plume has expanded) but decreasing the average concentration within the aquifer through dilution and increased biodegradation.

Although high hydraulic conductivity can result in plume expansion and migration, this same characteristic will also enhance the effectiveness of other remedial technologies, such as groundwater extraction, biosparging, and intrinsic remediation. For example, it should also be less expensive and time-consuming to capture and treat the contaminant plume using a network of extraction wells in areas of high hydraulic conductivity. Contaminant recovery may also be maximized when contaminants are not significantly sorbed to and retarded by phreatic soil. However, the TOC content of aquifer materials at Site 3 (0.029-0.098 percent) will tend to enhance sorption and slightly decrease the mobility of all BTEX compounds. The effectiveness of biosparging may also be increased in highly conductive aquifers because of reduced entry pressures and increased radius of influence. Greater hydraulic conductivity also increases the amount of contaminant mass traveling through the biosparging network. The DO introduced through biosparging can also enhance aerobic degradation of the dissolved contaminant mass.

The rapid movement of contaminants within the subsurface away from the source will also increase the effectiveness of natural biodegradation processes by distributing the contaminant mass into areas enriched with electron acceptors. To satisfy the requirements of indigenous microbial activity and intrinsic remediation, the aquifer must also provide an adequate and available carbon or energy source, electron acceptors, essential nutrients, proper ranges of pH, temperature, and redox potential.

Data collected as part of the field work phase of this demonstration project and described in Sections 3 and 4 of this document indicate that Site 3 is characterized by adequate and available carbon/energy sources and electron acceptors to support measurable biodegradation of BTEX contamination by indigenous microorganisms. DO, nitrate, ferric iron, sulfate, and carbon dioxide represent significant sources of electron acceptor capacity for the biodegradation of BTEX compounds at the site. Further, because fuel hydrocarbon-degrading microorganisms have been known to thrive under a wide range of temperature and pH conditions (Freeze and Cherry, 1979), the physical and chemical conditions of the groundwater and phreatic soil at Site 3 are not likely to inhibit microorganism growth.

Fuel hydrocarbon-degrading microorganisms are ubiquitous and as many as 28 hydrocarbon-degrading isolates (bacteria and fungi) have been discovered in different soil environments (Davies and Westlake, 1977; Jones and Eddington, 1968). Indigenous microorganisms have a distinct advantage over microorganisms injected into the subsurface to enhance biodegradation as indigenous microorganisms are well adapted to

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the physical and chemical conditions of the subsurface in which they reside (Goldstein *et al.*, 1985). Microbe addition was not considered a viable remedial technology for Site 3.

6.2.3.2 Potential Exposure Pathways

A pathway analysis identifies the human and ecological receptors that could potentially come into contact with site-related contamination and the pathways through which these receptors might be exposed. To have a complete exposure pathway, there must be a source of contamination, a mechanism(s) of release, a pathway of transport to an exposure point, an exposure point, and a receptor. If any of these elements does not exist, the exposure pathway is considered incomplete, and receptors cannot come into contact with site-related contamination. Evaluation of the potential long-term effectiveness of any remedial technology or remedial alternative as part of this demonstration project includes determining whether the approach will be sufficient and adequate to minimize plume expansion so that potential exposure pathways involving shallow groundwater are incomplete.

Assumptions about current and future land use at a site form the basis for identifying potential receptors, potential exposure pathways, reasonable exposure scenarios, and appropriate remediation goals. USEPA (1991) advises that the land use associated with the highest (most conservative) potential level of exposure and risk that can reasonably be expected to occur should be used to guide the identification of potential exposure pathways and to determine the level to which the site must be remediated. The source area consists of a Fire Training Area separate from other facilities at the Base. Base supply storage buildings are located approximately 300 feet northeast of Site 3, and a fuel pump station is located approximately 450 feet east of the Site. Undeveloped land is located to the north and west of the Site. The groundwater plume originating from Site 3 is migrating to the north-northwest, and has primarily impacted shallow groundwater underlying the undeveloped land. The plume has also partially impacted the area underlying the base supply storage buildings. Thus, the current land use within and downgradient of the contaminant plume is primarily undeveloped but partially industrial. The Kalamazoo River is located approximately 1.5 miles north of the Base.

Under reasonable current land use assumptions, potential receptors include only worker populations. It is unlikely that workers could be exposed to site-related contamination in phreatic soils or shallow groundwater unless this material was removed during future construction excavations or remedial activities. Shallow groundwater is not currently used to meet industrial demands at the Base. All on Base water demands are met with water supplied by the City of Battle Creek. Exposure pathways involving other environmental media such as shallow soils and soil gas in the source area were not considered as part of this project, but should be considered in overall site remediation decisions. Migration to and discharge of contaminated shallow groundwater into the Kalamazoo River could complete an exposure pathway to human or ecological receptors via dermal contact or possible ingestion, but model results suggest that it is very unlikely that detectable concentrations could reach the river.

Assumptions about hypothetical future land uses must also be made to ensure that the remedial technology or alternative considered for shallow groundwater at the site is

adequate and sufficient to provide long-term protection. No changes in land use are anticipated in the foreseeable future so use of an industrial land use assumption is the most appropriate. Thus, potential future receptors include only worker populations. The potential future exposure pathways involving workers are identical to those under current conditions provided shallow groundwater is not used to meet industrial water demands. In summary, the use of the intrinsic remediation technology at this site will require that the source area be maintained as industrial property and that restrictions on groundwater use be enforced in areas downgradient of Site 3. If source removal technologies such as soil vapor extraction, bioventing, free product recovery, biosparging or groundwater pump and treat are implemented, they will have some impact on the short- and long-term land use options and will require some level of institutional control and worker protection during remediation.

6.2.3.3 Remediation Goals for Shallow Groundwater

Model results suggest that BTEX compounds are not likely to move more than 720 feet downgradient of the source area, assuming contaminants are introduced into the aquifer at a constant rate. As the source area remediation proceeds via bioventing, and as residual product weathers, BTEX loading rates will decrease and the extent of BTEX migration will likely be much more limited than indicated by model results. Therefore, an area approximately 1,000 feet beyond the source cells has been identified as the POC for groundwater remedial activities because this appears to be beyond the maximum extent of future contaminant migration. This is a suitable location for monitoring and for demonstrating compliance with protective groundwater quality standards, such as promulgated groundwater MCLs.

This remedial strategy assumes that compliance with promulgated, single-point remediation goals is not necessary if site-related contamination does not pose a threat to human health or the environment (i.e., the exposure pathway is incomplete). Thus, the magnitude of required remediation in areas that can and will be placed under institutional control is different from the remediation that is required in areas that may be available for unrestricted use. The primary RAO for shallow groundwater within and downgradient of Site 3 is limited plume expansion to prevent exposure of downgradient receptors to concentrations of BTEX in groundwater at levels that pose a risk. This means that viable remedial alternatives must be able to achieve concentrations that minimize plume migration and/or expansion. The RAO for shallow groundwater at the POC is attainment of State of Michigan Generic Type B drinking water cleanup criteria values for each of the BTEX compounds listed in Table 6.1. However, the more lenient Generic Type C health-based cleanup criteria for industrial/commercial areas may apply, depending on future development of the Base. These values are also listed in Table 6.1 for purposes of comparison.

In summary, available data suggest that there is no complete potential exposure pathway involving shallow groundwater under current conditions. It is likely that no potential exposure pathways involving shallow groundwater would be complete under future land use assumptions, provided use of groundwater as a potable or industrial source of water is prohibited by institutional controls within the source area and within an area approximately 1,000 feet downgradient of the source area. Thus, institutional controls are likely to be a necessary component of any groundwater remediation strategy

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TABLE 6.1
POINT-OF-COMPLIANCE REMEDIATION GOALS
SITE 3 (FIRE TRAINING AREA) INTRINSIC REMEDIATION TS
MICHIGAN AIR NATIONAL GUARD
W.K. KELLOGG MEMORIAL AIRPORT
BATTLE CREEK, MICHIGAN

Compound	Michigan Type B Cleanup Criteria (µg/L)	Michigan Type C Cleanup Criteria (µg/L)
Benzene	1.2	5
Toluene	790	1000
Ethylbenzene	74	700
Total Xylenes	280	10,000

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for this site. The required duration of these institutional controls may vary depending on the effectiveness of the selected remedial technology at reducing contaminant mass and concentration in the groundwater.

6.2.4 Summary of Remedial Technology Screening

Several remedial technologies have been identified and screened for use in treating the shallow groundwater at Site 3. Table 6.2 identifies the initial remedial technologies considered as part of this demonstration and those retained for detailed comparative analysis. Screening was conducted systematically by considering the program objectives of the AFCEE intrinsic remediation demonstration, the physiochemical properties of the BTEX compounds, and other site-specific characteristics such as hydrogeology, land use assumptions, potential exposure pathways, and appropriate remediation goals. All of these factors will influence the technical effectiveness, implementation, and relative cost of technologies for remediating shallow groundwater underlying and migrating from the site. The remedial technologies retained for development of remedial alternatives and comparative analysis include institutional controls, intrinsic remediation, LTM, bioventing/soil vapor extraction, and biosparging.

6.3 BRIEF DESCRIPTION OF REMEDIAL ALTERNATIVES

This section describes how remedial technologies retained from the screening process were combined into two remedial alternatives for Site 3. Sufficient information on each remedial alternative has been provided to facilitate a comparative analysis of effectiveness, implementability, and cost in Section 6.4.

6.3.1 Alternative 1 - Continued Bioventing in Source Area, Intrinsic Remediation, and Institutional Controls with Long-Term Monitoring

Pilot-scale bioventing was conducted from September 1992 through October 1993 in the source area at Site 3. A single well bioventing system injected air into the subsurface and provided oxygen to approximately 7,800 cubic yards of the most contaminated unsaturated soils. The existing bioventing system can continue to be utilized as a source reduction method. Bioventing is preferred over soil vapor extraction because bioventing uses a low rate of air injection that does not create vapor emissions into the atmosphere. As indicated in Section 5.6.2, it has been estimated that the bioventing system will result in removal of 90 percent of the residual soil BTEX compounds within 3 years with an assumed proportional decrease in BTEX dissolution into shallow groundwater. To promote source reduction in the capillary fringe as well as the vadose zone, it is recommended that the bioventing system be run for approximately 4 years. During the bioventing pilot test, the water table was higher than normal. The increased diffusion of oxygen into the groundwater through bioventing, and normal water table fluctuations are expected to provide increased oxygenation to the capillary fringe and promote continued degradation of residual BTEX compounds.

Intrinsic remediation is achieved when naturally occurring attenuation mechanisms bring about a reduction in the total mass of a contaminant in the soil or dissolved in groundwater. Intrinsic remediation results from the integration of several subsurface attenuation mechanisms that are classified as either destructive or nondestructive.

TABLE 6.2

INITIAL TECHNICAL IMPLEMENTABILITY SCREENING OF
TECHNOLOGIES AND PROCESS OPTIONS FOR GROUND WATER REMEDIATION
SITE 3 (FIRE TRAINING AREA) INTRINSIC REMEDIATION TS
MICHIGAN AIR NATIONAL GUARD
W.K. KELLOGG MEMORIAL AIRPORT
BATTLE CREEK, MICHIGAN

General Response Action	Technology Type	Process Option	Implementability	Retain
Long-Term Monitoring	Periodic Ground Water Monitoring	Confirmation Wells	Many existing wells are available to confirm the progress of remediation.	Yes
		Point-of-Compliance Wells	Sufficient distance exists between the plume and point-of-compliance to locate several wells.	Yes
Institutional Controls	Ground Water Use Control	Land Use Control/Regulate Well Permits	Plume area is currently within the base boundary and land-use and ground water use are under base jurisdiction.	Yes
		Seal/Abandon Existing Wells	No production wells are known to exist in the existing or predicted plume area.	No
		Point-of-Use Treatment	No ground water is extracted from the plume area for any use.	No
	Public Education	Meetings/ Newsletters	Base public relations and environmental management offices have many information avenues to workers and residents.	Yes
Containment of Plume	Hydraulic Controls	Passive Drain Collection	No likely receptors downgradient of site. Installation could disrupt base operations.	No
		Minimum Pumping/Gradient Control	A line or semicircle of vertical pumping wells could be located along the leading edge of plume to intercept and halt the advance of the plume. No likely receptors downgradient of site.	No
	Physical Controls	Slurry Walls/Grout Curtains	Requires significant disruption of base operating area. Limited effectiveness.	No
		Sheet Piling	Requires significant disruption of base operating area. Limited effectiveness.	No
	Reactive/Semi-Permeable Barriers	Biologically Active Zones	Natural biodegradation of BTEX compounds can be stimulated by allowing contaminated ground water to flow through an aquifer zone which has enhanced oxygen and nutrient conditions.	No

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TABLE 6.2 (Continued)

INITIAL TECHNICAL IMPLEMENTABILITY SCREENING OF
TECHNOLOGIES AND PROCESS OPTIONS FOR GROUND WATER REMEDIATION
SITE 3 (FIRE TRAINING AREA) INTRINSIC REMEDIATION TS
MICHIGAN AIR NATIONAL GUARD
W.K. KELLOGG MEMORIAL AIRPORT
BATTLE CREEK, MICHIGAN

General Response Action	Technology Type	Process Option	Implementability	Retain
In Situ Treatment	Biological	Oxygen and Nutrient Enhanced Biodegradation (Biosparging)	Differs from biologically active zone in that oxygen and nutrients are injected upgradient of plume and allowed to migrate downgradient. In theory, this method can more rapidly reduce higher BTEX concentrations in and immediately downgradient of the source area. Not proven to be more effective than intrinsic remediation	Yes
	Chemical/Physical	Intrinsic Remediation	A combination of natural biological, chemical, and physical removal mechanisms which occur to varying degrees on every site. Ground water sampling at Site ST-3 indicates that this is a major, ongoing remediation process.	Yes
		Air Sparging (Volatilization)	Injection of air into contaminated aquifer creating a mass transfer of BTEX into air bubbles and into vadose zone. Limited radius of influence and short-circuiting are common problems.	No
Aboveground Ground Water Treatment	Ground Water Extraction	Vertical Pumping Wells	Entire groundwater plume is pumped by installing numerous wells with submersible pumps. High cost and major disruption to area. May require collection and treatment of water.	No
		Downgradient Horizontal Drains	See Passive Drain Collection.	No
	Biological	Bioreactors	High flow rates require excessive retention times and large reactors. BTEX is often volatilized in these systems.	No
	Chemical/Physical	Air Stripping	Cost-effective technology for removing varying concentrations of BTEX at higher flow rates. Permitting may be required for air emissions.	No
		Activated Carbon	Cost prohibitive for more concentrated BTEX. Creates a carbon disposal problem.	No
		UV/Ozone Reactors	High flow rates require excessive retention times and large, expensive reactors.	No

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TABLE 6.2 (Continued)
INITIAL TECHNICAL IMPLEMENTABILITY SCREENING OF
TECHNOLOGIES AND PROCESS OPTIONS FOR GROUND WATER REMEDIATION
SITE 3 (FIRE TRAINING AREA) INTRINSIC REMEDIATION TS
MICHIGAN AIR NATIONAL GUARD
W.K. KELLOGG MEMORIAL AIRPORT
BATTLE CREEK, MICHIGAN

General Response Action	Technology Type	Process Option	Implementability	Retain
Aboveground Treatment	Direct Discharge to Industrial Waste Water Treatment Plant (IWWTP)		Viable option when an IWWTP is available and capable of handling BTEX and hydraulic loading. Groundwater extraction is unlikely.	No
Treated Ground Water Disposal	Discharge to IWWTP or Sanitary Sewer	IWWTP	Viable option when access to sanitary sewer exists and hydraulic loading is acceptable. Ground water extraction is unlikely.	No
		Sanitary Sewer	Viable option when access to sanitary sewer exists and hydraulic loading is acceptable.	No
	Treated Ground Water Reinjection	Vertical Injection Wells	Not recommended due to clogging and high maintenance requirements.	No
		Injection Trenches	Require large trenches and can be subject to injection well permitting.	No
	Discharge to Surface Waters	Storm Drains	Viable option but generally requires NPDES or other discharge permit. Ground water extraction is unlikely.	No
Source Removal/Soil Remediation	Free Product Recovery	Dual-Pump Systems	Best suited for sites with >1 foot free product where aboveground ground water treatment already exists. No free product at site.	No
		Skimmer Pumps/Bailers/ Wicks	Best suited for sites with <1 foot free product where ground water pumping is undesirable.	No
		Total Fluids Pumping	Best suited for sites with thin saturated zones where excessive ground water will not be pumped.	No
		Bioslurping	Combined vapor extraction, bioventing and free product recovery system has been operated at some sites with limited success.	No
	Excavation/ Treatment	Biological Landfarming	Excavation is not feasible at this site due to surface structures and facility use.	No

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TABLE 6.2 (Concluded)
INITIAL TECHNICAL IMPLEMENTABILITY SCREENING OF
TECHNOLOGIES AND PROCESS OPTIONS FOR GROUND WATER REMEDIATION
SITE 3 (FIRE TRAINING AREA) INTRINSIC REMEDIATION TS
MICHIGAN AIR NATIONAL GUARD
W.K. KELLOGG MEMORIAL AIRPORT
BATTLE CREEK, MICHIGAN

General Response Action	Technology Type	Process Option	Implementability	Retain
	Excavation/ Treatment (cont'd)	Thermal Desorption	Excavation is not feasible at this site due to surface structures and site use.	No
	In Situ	Bioventing	Air injection to stimulate biodegradation of fuel residuals. Pilot system currently operating in source area.	Yes
		Soil Vapor Extraction	Vapor extraction has been successfully implemented at other sites. Requires expensive off-gas treatment.	Yes

Destructive attenuation mechanisms include biodegradation, abiotic oxidation, and hydrolysis. Nondestructive attenuation mechanisms include sorption, dilution (caused by dispersion and infiltration), and volatilization. In some cases, intrinsic remediation will reduce dissolved contaminant concentrations below numerical concentration goals, thus protecting human health and the environment. Based on the existing evidence of intrinsic remediation described in Section 4, these processes are occurring at Site 3 and will continue to reduce contaminant mass as the plume advances.

Results of model NSR suggest that if BTEX enters groundwater at a constant rate for an indefinite period of time, the dissolved plume should be completely degraded within approximately 14 years. The plume should not extend beyond the observed current maximum extent of 720 feet downgradient of the source area. This does not take into account source reduction through bioventing or weathering of the residual product trapped in the soil pores. Model BCSR assumes a significant reduction in the rates of BTEX loading into the groundwater. After 7 years of source removal, the Bioplume II model predicts that the combination of source reduction through bioventing and intrinsic remediation within the BTEX plume will completely degrade the plume. Under this scenario, model results also suggest that it is unlikely that BTEX compounds would migrate beyond the current extent of the plume, and that the plume front would stabilize approximately 250 feet downgradient of the source until total degradation is complete.

Implementation of Alternative 1 would require the use of institutional controls such as land use restrictions and LTM. Land use restrictions may include placing long-term restrictions on soil excavation within the source area and long-term restrictions on groundwater well installations within and downgradient of the source area. The intent of these restrictions would be to reduce potential receptor exposure to contaminants by legally restricting activities within areas affected by site-related contamination. The two previously discussed model scenarios delineate the minimum and maximum possible plume migration distances. Future plume migration and degradation will most likely result in conditions that fall between these limits. To be conservative, the results of model NSR should be considered in making decisions regarding groundwater monitoring and potential land use restrictions.

At a minimum, groundwater monitoring would be conducted annually as part of this remedial technology to evaluate the progress of natural attenuation processes. Based on the potential plume migration suggested by model NSR, it is unlikely that benzene concentrations exceeding the state MCL of 1.2 $\mu g/L$ (Table 6.1) would be present more that 720 feet downgradient of the source area (this would be true even if it were assumed that model contaminant concentrations are all benzene rather than total BTEX). Results of model BCSR suggest that, at its maximum extent, the BTEX plume would not exceed a distance of 720 feet beyond the source area.

Because there are no apparent downgradient receptors, POC wells should be placed downgradient of the modeled maximum extent (i.e., slightly more than 720 feet downgradient of the source area). In addition, LTM wells within, upgradient and immediately downgradient of the existing BTEX plume will be used to monitor the effectiveness of intrinsic remediation. LTM wells are further described in Section 7.2.1. Detection of benzene in excess of 1.2 $\mu g/L$ at the POC wells may require additional evaluation and modeling to assess BTEX migration or to determine if additional

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corrective action would be necessary. Land use restrictions would also require reevaluation.

Public education on the selected alternative will be developed to inform base personnel and residents of the scientific principles underlying source reduction and intrinsic remediation. This education could be accomplished through public meetings, presentations, press releases, and posting of signs where appropriate. Periodic site reviews could also be conducted every year using data collected from the long-term groundwater monitoring program. The purpose of these periodic reviews will be to evaluate the extent of contamination, assess contaminant migration and attenuation through time, document the effectiveness of source removal and institutional controls at the site, and reevaluate the need for additional remedial actions at the site.

6.3.2 Alternative 2 - Intrinsic Remediation and Institutional Controls with Long-Term Groundwater Monitoring

This alternative is identical to Alternative 1 except that bioventing would not continue. Rapid reduction of soil BTEX (and TPH) concentrations would not occur, and the source area would continue to contribute hydrocarbons to groundwater. Contaminant loading rates would eventually decrease, but more slowly than if bioventing were implemented.

As with Alternative 1, institutional controls and LTM would be required. Point-of-compliance wells would be installed in the same locations indicated in the previous section.

6.4 EVALUATION OF ALTERNATIVES

This section provides a comparative analysis of each of the remedial alternatives based on the effectiveness, implementability, and cost criteria. A summary of this evaluation is presented in Section 6.5.

6.4.1 Alternative 1 - Continued Bioventing in Source Area, Intrinsic Remediation, and Institutional Controls with Long-Term Monitoring

6.4.1.1 Effectiveness

Section 5 of this document presents the results of the Bioplume II model completed to support the intrinsic remediation alternative at Site 3. The potential impacts of continued BTEX dissolution on groundwater contamination over time were incorporated into one of the models (NSR) for this remedial alternative. The other model (BCSR) incorporated the effects of rapid and thorough reduction of BTEX loading rates by bioventing.

Model results predicted that natural attenuation mechanisms will significantly limit contaminant migration and reduce contaminant mass and toxicity. Benzene concentrations should not exceed the state MCL at the POC wells. The Bioplume II model is based upon numerous conservative assumptions and does not fully account for the anaerobic biodegradation caused by methanogenesis and other processes. In addition, it is highly unlikely that benzene concentrations in excess of 1.2 μg/L will reach the POC wells. Groundwater monitoring at the POC wells and other wells along the leading edge

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of the existing plume will ensure the protectiveness of this alternative. While this alternative would not cease to be protective if the benzene plume was intercepted by the POC wells, such an instance would indicate that site conditions should be reevaluated.

The effectiveness of this remedial alternative requires that excavations or drilling within the source area be conducted only by properly protected site workers. Reasonable land use assumptions for the plume area indicate that exposure is unlikely unless excavation or drilling activities bring saturated soil to the surface. Long-term land use restrictions will be required to ensure that shallow groundwater will not be pumped or removed for potable use within, and approximately 1,000 feet in all directions from, the existing BTEX plume. Existing health and safety plans should be enforced to reduce risks from operating existing source reduction technologies and from installing and monitoring additional POC wells.

Compliance with program goals is one component of the long-term effectiveness evaluation criterion. Alternative 1 will satisfy program objectives designed to promote intrinsic remediation as a component of site remediation and to scientifically document naturally occurring processes.

Alternative 1 is based on the effectiveness of enhanced naturally occurring processes that minimize contaminant migration and reduce contaminant mass over time, and the effectiveness of institutional controls. As described earlier, an investigation of the potential effectiveness of naturally occurring processes at Site 3 using field data and the Bioplume II model demonstrated that the BTEX plume migration will be significantly limited by natural attenuation processes. The sensitivity analysis completed on the Bioplume II model for this site (Section 5) suggests that even under the most conservative (i.e., worst-case) conditions, the naturally occurring processes at Site 3 should reduce contaminant migration so that the maximum distance traveled by the plume is unlikely to be beyond the proposed POC wells. The actual maximum migration distance is not likely to exceed the currently observed extent of 720 feet beyond the source area, due to the reduction of soil BTEX concentrations via bioventing.

Aside from the administrative concerns associated with long-term enforcement of long-term land use restrictions and long-term groundwater monitoring programs, this remedial alternative should provide reliable, continued protection. For cost comparison purposes. Alternative 1 includes the installation of four POC wells and three LTM wells. Each well would be constructed of two-inch (nominal diameter) PVC factory-slotted well screen and blank casing, and be completed to a depth of approximately 35 feet bgs. Based on Bioplume II modeling results, it is assumed that bioventing will continue for 4 years and that dissolved benzene concentrations will exceed state MCLs throughout the plume for approximately 7 years under Alternative 1. An additional 5 years of groundwater monitoring will be required to ensure that intrinsic remediation has uniformly reduced all BTEX compounds to levels below state MCLs.

6.4.1.2 Implementabilty

Alternative 1 is not technically difficult to implement. The bioventing system is currently in place and would likely only require inspection, maintenance, and reactivation. Installation of POC wells and annual groundwater monitoring are both

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standard procedures. Long-term management efforts will be required to ensure proper sampling procedures are followed. Periodic site reviews should be conducted to confirm the adequacy and completeness of LTM data and verify the effectiveness of this remediation approach. There may also be administrative concerns associated with long-term enforcement of groundwater use restrictions. Future land use within the source area may be impacted by leaving contaminated soil and groundwater in place. Regulators and the public will have to be informed of the benefits and limitations of the intrinsic remediation option. Educational programs are not difficult to implement, and the initial regulatory reaction to this alternative has been positive.

6.4.1.3 Cost

The cost of Alternative 1 is summarized in Table 6.3. Itemized costs are presented in Appendix E. Capital costs are limited to the construction of four new POC wells and three new LTM wells. For cost estimating purposes, POC wells were cost out the same as LTM wells. The cost of maintaining the full-scale bioventing system for 4 years are included in the $232,283 total present worth cost estimate for Alternative 1. Also included are the costs of maintaining institutional controls and long-term groundwater monitoring for a total of 12 years.

6.4.2 Alternative 2 - Intrinsic Remediation and Institutional Controls with Long-Term Groundwater Monitoring

6.4.2.1 Effectiveness

Because of the lack of a source removal component, the effectiveness of Alternative 2 is diminished compared to Alternative 1. However, this alternative also complies with the program goals because intrinsic remediation remains the predominant decontamination method for the site.

6.4.2.2 Implementability

Technical and administrative implementability concerns associated with the installation of POC and LTM wells, institutional controls, and long-term monitoring are identical to those discussed under Alternative 1.

6.4.2.3 Cost

The estimated capital and operating costs of Alternative 2 are shown in Table 6.4. Itemized costs are presented in Appendix E. The total present worth cost of Alternative 2 is $238,858. The cost of Alternative 2 differs from the costs of Alternative 1 by the omission of bioventing and extending the monitoring period to 20 years to verify that the plume continues to degrade and does not reach the POC wells. Based on model predictions, the plume will persist twice as long as with Alternative 1, but it should not migrate beyond the currently observed extent. Annual LTM would continue for 20 years to ensure that intrinsic remediation was reducing BTEX concentrations below MCLs throughout the plume. A monitoring period of 20 years was selected to allow sufficient time to confirm the weathering and degradation of residual LNAPL in the source area under natural conditions.

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TABLE 6.3
ALTERNATIVE 1 - COST ESTIMATE
SITE 3 (FIRE TRAINING AREA) INTRINSIC REMEDIATION TS
MICHIGAN AIR NATIONAL GUARD
W.K. KELLOGG MEMORIAL AIRPORT
BATTLE CREEK, MICHIGAN

Capital Costs	Cost
Design/Construct Four POC Wells and Three LTM Wells	$27,000
Operation, Maintenance and Monitoring Costs (Annual)	**Annual Cost**
Operate and Maintain Bioventing System (4 years)	$54,608
Conduct Annual Groundwater Monitoring of 9 wells (12 years)	$53,180
Maintain Institutional Controls/Public Education (12 years)	$44,316
Project Management and Regulatory Reporting (12 years)	$53,180
Present Worth of Alternative 1 [a/]	**$232,283**

[a/] Based on an annual inflation factor of 5 percent.

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TABLE 6.4
ALTERNATIVE 2 - COST ESTIMATE
SITE 3 (FIRE TRAINING AREA) INTRINSIC REMEDIATION TS
MICHIGAN AIR NATIONAL GUARD
W.K. KELLOGG MEMORIAL AIRPORT
BATTLE CREEK, MICHIGAN

Capital Costs	Cost
Design/Construct Four POC Wells and Three LTM Wells	$27,000

Operation, Maintenance and Monitoring Costs (Annual)	Annual Cost
Conduct Annual Groundwater Monitoring of 9 wells (20 years)	$74,773
Maintain Institutional Controls/Public Education (20 years)	$62,311
Project Management and Regulatory Reporting (20 years)	$74,773
Present Worth of Alternative 2 [a]	**$238,858**

[a] Based on an annual inflation factor of 5 percent.

6.5 RECOMMENDED REMEDIAL APPROACH

Two remedial alternatives have been evaluated for remediation of the shallow groundwater at Site 3. Components of the alternatives evaluated include bioventing, intrinsic remediation with LTM, and institutional controls. Table 6.5 summarizes the results of the evaluation based upon effectiveness, implementability, and cost criteria. Based on this evaluation, the Air Force recommends Alternative 1 as achieving the best combination of risk reduction and cost effectiveness.

A bioventing system is already in place, and the benefits of continued operation for 4 years to provide source reduction will result in a decreased monitoring time frame and lower costs associated with LTM. Bioventing also reduces contaminant mass and risk in vadose soils and provides enhanced oxygen exchange across the water table to induce biodegradation of dissolved BTEX. Based on all effectiveness criteria, Alternative 1 will make maximum use of intrinsic remediation mechanisms to reduce plume migration and toxicity while providing the added benefits of enhanced *in situ* soil remediation in the source area and the introduction of additional oxygen into the groundwater in the vicinity of the bioventing wells.

TABLE 6.5
SUMMARY OF REMEDIAL ALTERNATIVES EVALUATION
GROUND WATER REMEDIATION
SITE 3 (FIRE TRAINING AREA) INTRINSIC REMEDIATION TS
MICHIGAN AIR NATIONAL GUARD
W.K. KELLOGG MEMORIAL AIRPORT
BATTLE CREEK, MICHIGAN

Remedial Alternative	Effectiveness	Implementability	Present Worth Cost Estimate
Alternative 1			
- Continued Bioventing - Intrinsic Remediation - Long-Term Monitoring	Continued bioventing will gradually remove BTEX source. Contaminant mass, volume and toxicity will be significantly reduced over next 4 years. MCL for benzene not likely to be exceeded at POC.	Readily implementable. Long-term management, ground water use controls and monitoring required for an estimated 12 years. Minimal exposure of site workers if excavation is carefully controlled in source area.	$232,283
Alternative 2			
- Intrinsic Remediation - Long-Term Monitoring	Similar to Alternative 1, with the omission of bioventing. Contaminant mass, volume, and toxicity will be reduced, but more slowly than in Alternative 1. Potential for MCLs to be exceeded at POC.	Readily implementable. Long-term management, ground water controls, and monitoring required for an estimated 20 years. If MCLs exceeded at POC, additional remedial work may be required.	$238,858

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6-20

Both of the remedial alternatives are implementable; however, Alternative 1 is less expensive, more effectively reduces potential hydrocarbon migration and toxicity, and should be acceptable to the public and regulatory agencies because it is protective of human health and the environment and reduces soil and groundwater contamination in a shorter time frame. Implementation of Alternative 1 will require land use and groundwater use controls to be enforced for approximately 12 years, along with groundwater monitoring for the same period.

The final evaluation criterion used to compare each of the two remedial alternatives was cost. It is the opinion of the Air Force that Alternative 1 provides a cost effective means to both reduce contaminant mass and decrease the total period of monitoring required while providing sufficient protection to both the public and the environment.

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SECTION 7

LONG-TERM MONITORING PLAN

7.1 OVERVIEW

In keeping with the requirements of the preferred remedial alternative for Site 3 (continued bioventing and intrinsic remediation with LTM), a long-term groundwater monitoring plan should be developed. The purpose of this component of the preferred remedial alternative for Site 3 is to assess site conditions over time, confirm the effectiveness of bioventing and naturally occurring processes at reducing contaminant mass and minimizing contaminant migration, and evaluate the need for additional remediation.

To demonstrate attainment with both levels of site-specific remediation goals and to verify the accuracy of the Bioplume II model developed for Site 3, the LTM plan consists of identifying the location of two separate groundwater monitoring networks and developing a groundwater sampling and analysis strategy. The strategy described in this section is designed to monitor plume migration over time and to verify that intrinsic remediation is occurring at rates sufficient to protect potential receptors. In the event that data collected under this long-term program indicate that the selected alternative is insufficient to protect human health and the environment, this plan also describes contingency controls to augment the beneficial effects of intrinsic remediation.

7.2 MONITORING NETWORKS

Two separate sets of wells (LTM and POC) are recommended at Site 3 as part of the intrinsic remediation remedial alternative. All wells would be screened within the shallow aquifer

7.2.1 Long-Term Monitoring Wells

Proposed and existing LTM wells, located upgradient, within, and downgradient of the observed BTEX plume, would be used to assess the results of the Bioplume II modeling effort and to ensure that natural attenuation is occurring at rates sufficient to minimize plume expansion (i.e., meet the first level of remediation concentration goals for the site). One LTM well would be installed upgradient of the existing BTEX plume to define an upgradient boundary and establish plume control. Two additional LTM wells, installed as a nested pair downgradient of the BTEX plume, would be used to monitor for the possible downward migration of the dissolved-phase hydrocarbon plume. One upgradient and downgradient LTM well would be completed with 10-foot screens, approximately 5 feet of which would extend below the water table. The other

7-1

downgradient LTM well (i.e., the other well comprising the nested pair) would be completed with a 5 foot screen positioned further below the ground water table. The recommended locations of these wells are shown on Figure 7.1. The recommended completion configuration is shown on Figure 7.2.

Existing monitoring points ESMP-3 and ESMP-11, located within the BTEX plume, should also be used as LTM wells. Monitoring point ESMP-3 would be used to monitor conditions in the anaerobic treatment zone, while monitoring point ESMP-11 would be used to monitor conditions within the aerobic treatment zone. All LTM wells, existing and recommended, should be sampled for the parameters identified in Table 7.1.

7.2.2 Point-of-Compliance Wells

Four POC monitoring wells are recommended for installation approximately 300 feet downgradient of the existing BTEX plume to verify that contaminated groundwater exceeding state MCLs does not migrate beyond the area under institutional control. The locations of these wells are shown on Figure 7.1. Although model results suggest that the contaminant plume will not migrate to or beyond the proposed POC monitoring wells at concentrations exceeding state MCLs, these POC wells provide the means to demonstrate protection of human health and the environment and compliance with site-specific remediation goals. All POC wells should be sampled for the parameters identified in Table 7.2.

All four POC monitoring wells should be installed downgradient of the existing BTEX plume: two completed as single installations at separate locations, and two completed as a nested pair at the same location (Figure 7.1). The two wells comprising the nested pair would be used to monitor for the possible downward migration of the dissolved-phase hydrocarbon plume. One well at each location would be completed with 10-foot screens, approximately 5 feet of which would extend below the water table. The other well (i.e., the other well comprising the nested pair) would be completed with a 5 foot screen positioned further below the ground water table. The recommended completion configuration is shown on Figure 7.2.

7.3 GROUNDWATER SAMPLING

To ensure that sufficient contaminant removal is occurring at Site 3 to protect human health and the environment and meet site-specific remediation goals, the long-term groundwater monitoring plan includes a comprehensive sampling and analysis plan. Both LTM and POC wells should be sampled and analyzed annually to verify that naturally occurring processes are effectively reducing contaminant mass and mobility. Reductions in toxicity would be implied by mass reduction. The sampling and analysis plan should also be aimed at assuring intrinsic remediation can achieve site-specific remediation concentration goals for BTEX compounds and protect human health and the environment.

7.3.1 Analytical Protocol

All LTM and POC wells in the LTM program should be sampled and analyzed to determine compliance with chemical-specific remediation goals and to verify the

7-2

POC

POC

POC

LTM

ESMP-12

MW-6

ESMP-11 / LTM

ESMP-6

ESMP-5

MW-5

ESMP-4

6940   6941

ESMP-3

ESMP-7   LTM   MW-4

ESMP-2   MW-3

ESMP-10

MW-2   VW-1   ESMP-9

ESMP-13   ESMP-1

MW-1

ESMP-8

LTM

FUEL STORAGE TANKS

AUTO MAINT 6988

Lot A

BASE SUPPLY STORAGE

BC6-MW3   MOBILITY STORAGE 6909   C.E. BLDG 6910

FUEL PUMP STATION 6907

R-9 FILL STANDS   PO

N

LEGEND

LTM ◉   PROPOSED LTM NESTED WELL PAIR

LTM ⊕   PROPOSED LTM WELL

POC ◙   PROPOSED POC NESTED WELL PAIR

POC ⊗   PROPOSED POC WELL

ESMP-1 ✦   MONITORING POINT

MW-1 ⊕   MONITORING WELL

VW-1 ▲   BIOVENTING VENT WELL

⬭   FIRE TRAINING AREA

0   75   150   300
FEET

FIGURE 7.1

PROPOSED LOCATIONS OF LTM AND POC WELLS

Site 3 (Fire Training Area)
Intrinsic Remediation TS
Michigan Air National Guard,
W.K. Kellogg Airport
Battle Creek, Michigan

PARSONS ENGINEERING SCIENCE, INC.

Denver, Colorado

LOCKABLE STEEL
PROTECTIVE CASING

CONCRETE

GROUND SURFACE

BENTONITE SEAL

BLANK CASING
2" DIAMETER SCH 40 PVC.

10−20 SILICA SAND

10' OF 2" DIAMETER SCH 40 PVC
SCREEN W/THREADED JOINTS
SLOT SIZE = 0.010"

END CAP

BOREHOLE DIAMETER: ———— 8" ——

NOT TO SCALE
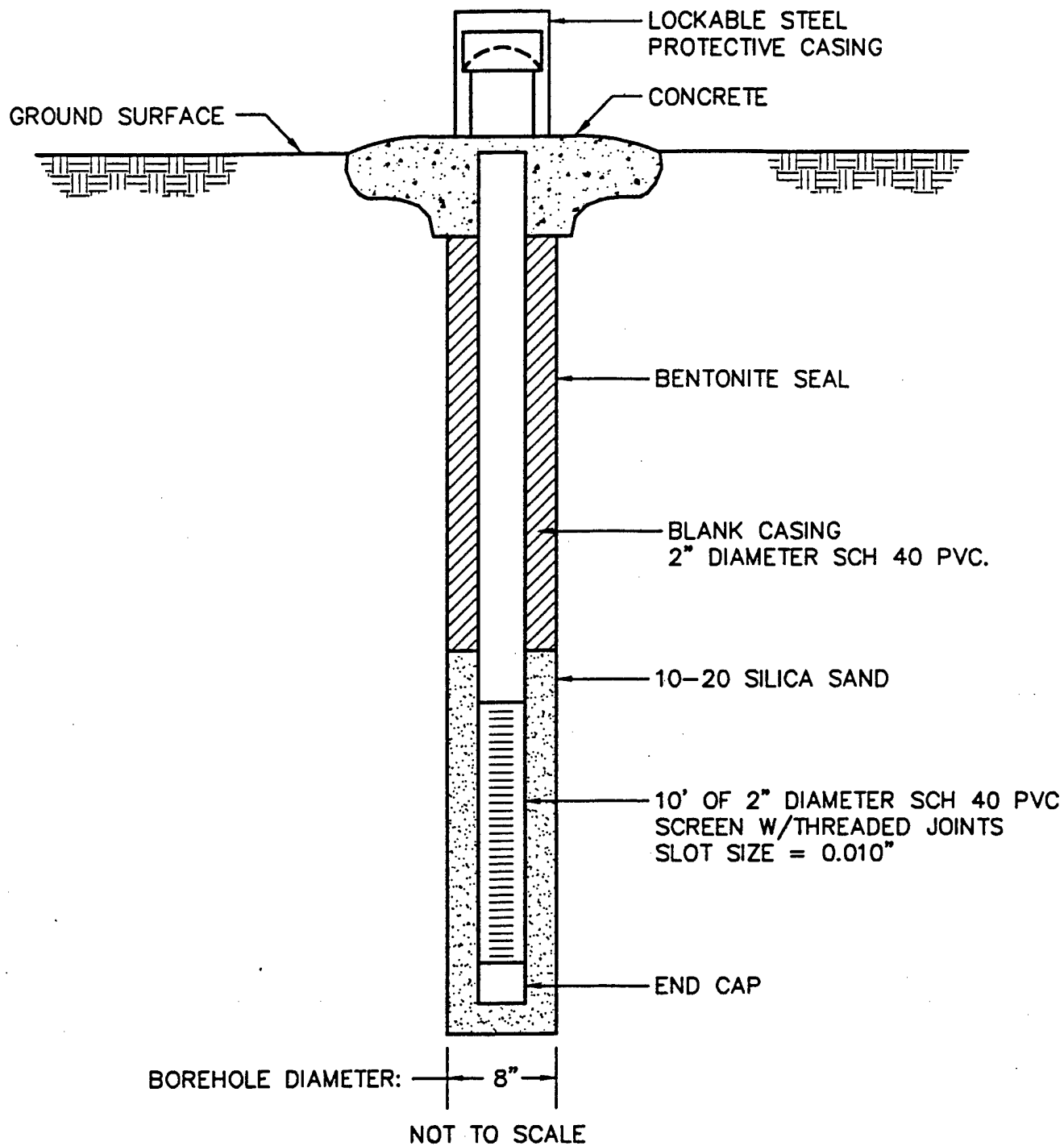
FIGURE 7.2

**PROPOSED MONITORING WELL
COMPLETION DIAGRAM**

Site 3 (Fire Training Area)
Intrinsic Remediation TS
Michigan Air National Guard, W.K. Kellogg Airport
Battle Creek, Michigan

**PARSONS
ENGINEERING SCIENCE, INC.**

Denver, Colorado

TABLE 7.1
LONG-TERM MONITORING ANALYTICAL PROTOCOL
SITE 3 (FIRE TRAINING AREA) INTRINSIC REMEDIATION TS
MICHIGAN AIR NATIONAL GUARD
W.K. KELLOGG MEMORIAL AIRPORT
BATTLE CREEK, MICHIGAN

Analyte	Method/Reference	Comments	Data Use	Recommended Frequency of Analysis	Sample Volume, Sample Container, Sample Preservation	Field or Fixed-Base Laboratory
Ferrous (Fe²⁺)	Colorimetric A3500-Fe D	Field only	Elevated ferrous iron concentrations may be indicative of the anaerobic biodegradation process of iron reduction	Annually	Collect 100 mL of water in a glass container; acidify with hydrochloric acid per method	Field
Ferrous (Fe²⁺)	Colorimetric HACH 25140-25	Alternate method; field only	Elevated ferrous iron concentrations may be indicative of the anaerobic biodegradation process of iron reduction	Annually	Collect 100 mL of water in a glass container	Field
Temperature	E170.1	Field only	Metabolism rates for microorganisms depend on temperature	Annually	N/A	Field
Dissolved Oxygen	Dissolved oxygen meter	Refer to Method A4500 for a comparable laboratory procedure	The oxygen concentration is a data input to the Bioplume II model; concentrations less than 1 mg/L generally indicate an anaerobic pathway	Annually	Collect 300 mL of water in biochemical oxygen demand bottles; analyze immediately; alternately, measure dissolved oxygen in situ	Field
pH	E150.1/SW9040, direct reading meter	Protocols/Handbook methods[a]	Aerobic and anaerobic processes are pH-sensitive	Annually	Collect 100–250 mL of water in a glass or plastic container; analyze immediately	Field
Conductivity	E120.1/SW9050, direct reading meter	Protocols/Handbook methods	General water quality parameter used as a marker to verify that site samples are obtained from the same ground water system	Annually	Collect 100–250 mL of water in a glass or plastic container	Field
Nitrate (NO₃⁻¹)	IC method E300 or method SW9056; colorimetric, method E353.2	Method E300 is a Handbook method; method SW9056 is an equivalent procedure	Substrate for microbial respiration if oxygen is depleted	Annually	Collect up to 40 mL of water in a glass or plastic container; cool to 4°C; analyze within 48 hours	Fixed-base

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TABLE 7.1 (Continued)
LONG-TERM MONITORING ANALYTICAL PROTOCOL
SITE 3 (FIRE TRAINING AREA) INTRINSIC REMEDIATION TS
MICHIGAN AIR NATIONAL GUARD
W.K. KELLOGG MEMORIAL AIRPORT
BATTLE CREEK, MICHIGAN

Analyte	Method/Reference	Comments	Data Use	Recommended Frequency of Analysis	Sample Volume, Sample Container, Sample Preservation	Field or Fixed-Base Laboratory
Sulfate (SO_4^{-2})	IC method E300 or method SW9056 or HACH SulfaVer 4 method	Method E300 is a Handbook method; method SW9056 is an equivalent procedure. HACH method is Photometric	Substrate for anaerobic microbial respiration	Annually	Collect up to 40 mL of water in a glass or plastic container; cool to 4°C	Fixed-base or field (for HACH method)
Redox potential	A2580 B	Measurements are made with electrodes; results are displayed on a meter; samples should be protected from exposure to atmospheric oxygen	The redox potential of ground water influences and is influenced by biologically mediated reactions; the redox potential of ground water may range from more than 200 mV to less than -400 mV	Annually	Collect 100–250 mL of water in a glass container, filling container from bottom; analyze immediately	Field
Methane	RSKSOP-114 modified to analyze water samples for methane by headspace sampling with dual thermal conductivity and flame ionization detection.	Method published and used by the US Environmental Protection Agency Robert S. Kerr Laboratory	The presence of methane suggests BTEX degradation via an anaerobic pathway utilizing carbon dioxide (carbonate) as the electron acceptor (methanogenesis)	Annually	Collect water samples in 40 mL volatile organic analysis (VOA) vials with butyl gray/Teflon-lined caps (zero headspace); cool to 4°C	Fixed-base
Aromatic hydrocarbons (BTEX)	Purge and trap GC method SW8020	Handbook method; analysis may be extended to higher molecular weight alkylbenzenes	BTEX is the primary target analyte for monitoring natural attenuation; BTEX concentrations must also be measured for regulatory compliance	Annually	Collect water samples in a 40 mL VOA vial with zero headspace; cool to 4°C; add hydrochloric acid to pH 2	Fixed-base

a/ Protocol methods are presented by Wiedemeier et al., 1994

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TABLE 7.2
POINT-OF-COMPLIANCE MONITORING ANALYTICAL PROTOCOL
SITE 3 (FIRE TRAINING AREA) INTRINSIC REMEDIATION TS
MICHIGAN AIR NATIONAL GUARD
W.K. KELLOGG MEMORIAL AIRPORT
BATTLE CREEK, MICHIGAN

Analyte	Method/Reference	Comments	Data Use	Recommended Frequency of Analysis	Sample Volume, Sample Container, Sample Preservation	Field or Fixed-Base Laboratory
Temperature	E170.1	Field only	Well development	Annually	N/A	Field
Dissolved Oxygen	Dissolved oxygen meter	Refer to method A4500 for a comparable laboratory procedure	The oxygen concentration is a data input to the Bioplume model; concentrations less than 1 mg/L generally indicate an anaerobic pathway	Annually	Collect 300 mL of water in biochemical oxygen demand bottles; analyze immediately; alternately, measure dissolved oxygen in situ	Field
pH	E150.1/SW9040, direct reading meter	Protocols/Handbook methods[a]	Aerobic and anaerobic processes are pH-sensitive	Annually	Collect 100–250 mL of water in a glass or plastic container; analyze immediately	Field
Conductivity	E120.1/SW9050, direct reading meter	Protocols/Handbook methods	General water quality parameter used as a marker to verify that site samples are obtained from the same ground water system	Annually	Collect 100–250 mL of water in a glass or plastic container	Field
Redox potential	A2580 B	Measurements are made with electrodes; results are displayed on a meter; samples should be protected from exposure to atmospheric oxygen	The redox potential of ground water influences and is influenced by biologically mediated reactions; the redox potential of ground water may range from more than 200 mV to less than -400 mV	Annually	Collect 100–250 mL of water in a glass container, filling container from bottom; analyze immediately	Field
Aromatic hydrocarbons (BTEX)	Purge and trap GC method SW8020	Handbook method; analysis may be extended to higher molecular weight alkylbenzenes	BTEX is the primary target analyte for monitoring natural attenuation; BTEX concentrations must also be measured for regulatory compliance	Annually	Collect water samples in a 40 mL VOA vial with zero headspace; cool to 4°C; add hydrochloric acid to pH 2	Fixed-base

[a] Protocol methods are presented by Wiedemeier et al., 1994

effectiveness of intrinsic remediation at the site. Water level measurements should be made during each sampling event. All groundwater samples should be analyzed for the parameters listed in Tables 7.1 and 7.2. A site-specific groundwater sampling and analysis plan should be prepared prior to initiating the LTM program.

7.3.2 Sampling Frequency

Each of the LTM and POC sampling points should be sampled once each year for 12 years. Because the initial bioventing results and modeling results indicate significant contaminant mass reduction during the suggested three year continued bioventing period, the data collected from annual sampling during the first 4 years should be evaluated to determine if the sampling frequency can be changed to a biannual period. If the data collected during this time period supports the anticipated effectiveness of the intrinsic remediation alternative at this site, the sampling frequency can be reduced to once every 2 years for all wells in the LTM program. Reduced sampling would result in additional cost savings. At the end of the suggested 12 year monitoring period, the data should again be evaluated to determine if the sampling should be continued on a biannual basis or discontinued. If the data collected at any time during the monitoring period indicate the need for additional remedial activities at the site, sampling frequency should be adjusted accordingly.

7.4 BIOVENTING OPERATION AND MAINTENANCE

To ensure that the bioventing system is operating effectively, annual monitoring of the system is recommended. The annual monitoring would be in addition to the normal ongoing maintenance of the physical unit performed by the Base. The monitoring schedule includes *in situ* respiration tests after 12 months of operation; annual soil gas sampling with both field and laboratory analyses; and soil sampling at the end of the recommended 4-year period of operation. The monitoring should be aimed at documenting continued biologic activity based on levels of oxygen and carbon dioxide and the continued reduction of contaminant based on concentrations of VOCs in the soil gas.

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SECTION 8

CONCLUSIONS AND RECOMMENDATIONS

This report presents the results of a TS conducted to evaluate the use of intrinsic remediation (natural attenuation) for remediation of fuel-hydrocarbon-contaminated groundwater at the Fire Training Area (Site 3), MANG facility at W.K. Kellogg Memorial Airport, Battle Creek, Michigan. Specifically, the finite-difference groundwater model Bioplume II was used in conjunction with site-specific geologic, hydrologic, and laboratory analytical data to simulate the migration and oxygen-limited biodegradation of fuel hydrocarbon compounds dissolved in groundwater. Groundwater contaminant and geochemical data strongly suggest that aerobic biodegradation of fuel hydrocarbons is occurring at the site. In addition, the data also suggest that anaerobic biodegradation is occurring via nitrate reduction, ferric iron reduction, sulfate reduction, and methanogenesis.

To collect the data necessary for the intrinsic remediation demonstration, Parsons ES and USEPA researchers collected soil and groundwater samples from the site. Physical and chemical data collected under this program were supplemented with data collected during previous site characterization events. Site-specific geologic, hydrologic, and laboratory analytical data were then used in the Bioplume II numerical groundwater model to simulate the effects of advection, dispersion, sorption, and biodegradation on the fate and transport of the dissolved BTEX plume. Extensive site-specific data were used for model implementation. Model parameters that could not be obtained from existing site data were estimated using widely accepted literature values for sediments similar to those found at the site. Conservative aquifer parameters, and the assumption that only aerobic biodegradation would occur, were used to construct the Bioplume II model for this study, and therefore, the model results presented herein represent a worst-case scenario.

For one simulation (model NSR), it was assumed that BTEX compounds would enter the aquifer at a constant rate. That rate was the same rate used to produce the initial calibrated model. Therefore, the results presented for model NSR represent a worst-case scenario in which, after about 14 years, the rate of natural attenuation exceeds the rate of contaminant addition to the aquifer resulting in total degradation of the BTEX plume. For a second simulation (model BCSR), it was assumed that BTEX loading rates were significantly decreased by bioventing over a 3-year period. Results for BCSR represent an optimistic, but still conservative scenario in which dissolved BTEX compounds would degrade to below detectable concentrations in 7 years.

Actual dissolved BTEX degradation rates observed during LTM at the site will probably be greater than predicted by model NSR and less than predicted by model

BCSR. This will result in faster removal rates of the BTEX compounds and a shorter plume migration distance than predicted by model NSR. In addition, bioventing should increase the diffusion of oxygen into groundwater and across the soil gas-water interface. Increased diffusion causes increased ground-water reaeration, which further enhances biodegradation of dissolved petroleum hydrocarbons (Barr, 1993).

The results of this study suggest that natural attenuation of BTEX compounds is occurring at Site 3 to the extent that the dissolved concentrations of these compounds in groundwater should be reduced to levels below current regulatory guidelines long before potential downgradient receptors could be adversely affected (i.e., the potential contaminant migration pathway will not be complete for any of the potential receptors described in Section 6.2). Based on the distance to potential downgradient receptors (at least 1.5 miles to the Kalamazoo River) and rates of BTEX plume migration and degradation predicted by models NSR and BCSR, Parsons ES is recommending continued bioventing coupled with natural attenuation, institutional controls, and LTM as the remedial option for BTEX-impacted groundwater near Site 3. Construction activities and groundwater use in and downgradient from the source area should be restricted for a period of approximately 12 years.

To verify the results of the Bioplume II modeling effort, and to ensure that natural attenuation is occurring at rates sufficient to protect potential downgradient receptors, groundwater from existing monitoring point ESMP-3 and both existing monitoring points at ESMP-11, and from two proposed LTM wells should be sampled annually and analyzed for the parameters listed in Tables 7.1 and 7.2. In addition, three POC groundwater monitoring wells should be installed downgradient from the predicted maximum travel distance of the BTEX plume. Figure 7.1 shows suggested locations for the three new POC monitoring wells and the two new LTM wells. These wells should be sampled annually for 4 years and biannually for 8 years, for a total monitoring period of 12 years, and the samples should be analyzed for the parameters listed in Tables 7.1 and 7.2. If dissolved BTEX concentrations in groundwater in the POC wells are found to exceed the Michigan Generic Type B cleanup criteria of 1.2 µg/L for benzene, 790 µg/L for toluene, 74 µg/L for ethylbenzene, or 290 µg/L for total xylenes, additional evaluation or corrective action may be necessary at this site.

8-2

SECTION 9

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APPENDIX A

CONE PENETROMETER LOGS, MONITORING POINT
INSTALLATION RECORDS, AND SLUG TEST RESULTS

CONE PENETROMETER LOG

Sheet 1 of 1

BORING NO.: ESSB-4 CONTRACTOR: USACE DATE SPUD: 8/18/94
CLIENT: AFCEE RIG TYPE: CPT DATE CMPL.: 8/18/94
JOB NO.: 722450.10 DRLG METHOD: CPT ELEVATION: 919.12 ft msl
LOCATION: BATTLE CREEK ANG BORING DIA.: 1.77" TEMP: 70 F
GEOLOGIST: TH/SH DRLG FLUID: NONE WEATHER: Sunny
COMMENTS:

Elev (ft)	Depth (ft)	Pro-file	US CS	Geologic Description	Sample No.	Sample Depth (ft)	Sample Type	Penet Res	PID (ppm)	TLV (ppm)	TOTAL BTEX (ppm)	TPH (ppm)
	1		SP	Fine to medium poorly sorted SAND Occurence of small pebbles		2–2.5	G		6			
	5											
	10							N O T				
	15		SP	Fine to medium poorly sorted SAND		14–14.5	G	M E A S U R E D	>1000			
	20		SP	Gravelly SAND, little or no fines		21.5–22	G					
	25											
	30											
	35											

NOTES

bgs – Below Ground Surface
GS – Ground Surface
TOC – Top of Casing
NS – Not Sampled
SAA – Same As Above

SAMPLE TYPE

D – DRIVE
C – CORE
G – GRAB

▼ Water level drilled

CONE PENETROMETER LOG

Site 3 (Fire Training Area)
Intrinsic Remediation RAP
Michigan Air National Guard, WK Kellogg Airport
Battle Creek, Michigan

PARSONS
ENGINEERING SCIENCE, INC.
Denver, Colorado

M:\45010\BORELOGS\94DN1289, 1/13/95 at 7:15

CONE PENETROMETER LOG

BORING NO.: ESSB-6   CONTRACTOR: USACE   DATE SPUD: 8/18/94
CLIENT: AFCEE   RIG TYPE: CPT   DATE CMPL.: 8/18/94
JOB NO.: 722450.10   DRLG METHOD: CPT   ELEVATION: 919.26 ft msl
LOCATION: BATTLE CREEK ANG   BORING DIA.: 1.77"   TEMP: 70 F
GEOLOGIST: TH/SH   DRLG FLUID: NONE   WEATHER: Sunny
COMMENTS: Cobbel layer was breached on this location to achieve a deeper soil sample

Elev (ft)	Depth (ft)	Profile	USCS	Geologic Description	Sample No.	Sample Depth (ft)	Sample Type	Penet Res	PID (ppm)	TLV (ppm)	TOTAL BTEX (ppm)	TPH (ppm)
			SP	Poorly sorted SAND with gravel Gray with slight hydrocarbon odor		2.75–3.5	G					
	5		SP	Poorly sorted SAND with gravel Saturated gray sand with slight hyd. odor		4–4.5	G	N				
	10							O				
	15		SP	Fine to medium poorly sorted SAND		13.5–14.25	G	T				
	20		SP	Fine to medium poorly sorted SAND Slight hydrocarbon odor		21–21.5	G	M E A S U R E D				
	25		SP	Poorly sorted SAND with gravel Gray, saturated, hydrocarbon odor		27–27.5	G					
	30											
	35											

NOTES

bgs – Below Ground Surface
GS – Ground Surface
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NS – Not Sampled
SAA – Same As Above

SAMPLE TYPE

D – DRIVE
C – CORE
G – GRAB

▼ Water level drilled

CONE PENETROMETER LOG

Site 3 (Fire Training Area)
Intrinsic Remediation RAP
Michigan Air National Guard, W.K. Kellogg Airport
Battle Creek, Michigan

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

CONE PENETROMETER LOG

BORING NO.: ESSB-1 CONTRACTOR: USACE DATE SPUD: 8/17/94
CLIENT: AFCEE RIG TYPE: CPT DATE CMPL.: 8/17/94
JOB NO.: 722450.10 DRLG METHOD: CPT ELEVATION: 918.76 ft msl
LOCATION: BATTLE CREEK ANG BORING DIA.: 1.77" TEMP: 80 F
GEOLOGIST: TH/SH DRLG FLUID: NONE WEATHER: Sunny
COMMENTS:

Elev (ft)	Depth (ft)	Pro-file	US CS	Geologic Description	Sample No.	Sample Depth (ft)	Sample Type	Penet Res	PID(ppm)	TLV(ppm)	TOTAL BTEX(ppm)	TPH (ppm)
	1											
	5											
	10							N O T				
	15							M E A S U R E D				
	20											
▼	25		SP	Fine to medium poorly sorted SAND Black sandy stringers		26–26.5	G					
			SP	Fine to medium poorly sorted SAND No stringers		27.5–28	G					
	30											
	35											

NOTES
bgs – Below Ground Surface
GS – Ground Surface
TOC – Top of Casing
NS – Not Sampled
SAA – Same As Above

SAMPLE TYPE
D – DRIVE
C – CORE
G – GRAB

▼ Water level drilled

CONE PENETROMETER LOG

Site 3 (Fire Training Area)
Intrinsic Remediation RAP
Michigan Air National Guard, W.K. Kellogg Airport
Battle Creek, Michigan

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

CONE PENETROMETER LOG

Sheet 1 of 1

BORING NO.: ESSB-2 CONTRACTOR: USACE DATE SPUD: 8/18/94
CLIENT: AFCEE RIG TYPE: CPT DATE CMPL.: 8/18/94
JOB NO.: 722450.10 DRLG METHOD: CPT ELEVATION: 919.09 ft msl
LOCATION: BATTLE CREEK ANG BORING DIA.: 1.77" TEMP: 70 F
GEOLOGIST: TH/SH DRLG FLUID: NONE WEATHER: Sunny
COMMENTS:

Elev (ft)	Depth (ft)	Pro-file	US CS	Geologic Description	Sample No.	Sample Depth (ft)	Sample Type	Penet Res	PID(ppm)	TLV(ppm)	TOTAL BTEX(ppm)	TPH (ppm)
	1		SP	Fine to medium poorly sorted SAND		2–2.5	G					
	5							N				
	10							O				
	15		SP	Fine to medium poorly sorted SAND		14–14.5	G	T				
	20							M E A				
	25							S U R				
	30							E D				
	35											

NOTES
bgs — Below Ground Surface
GS — Ground Surface
TOC — Top of Casing
NS — Not Sampled
SAA — Same As Above

SAMPLE TYPE
D — DRIVE
C — CORE
G — GRAB

▼ Water level drilled

CONE PENETROMETER LOG

Site 3 (Fire Training Area)
Intrinsic Remediation RAP
Michigan Air National Guard, W.K. Kellogg Airport
Battle Creek, Michigan

PARSONS ENGINEERING SCIENCE, INC.

Denver, Colorado

M:\45010\BORELOGS\94DN1287, 1/12/95 at 7:45

CONE PENETROMETER LOG

Sheet 1 of 1

BORING NO.: ESSB-5   CONTRACTOR: USACE   DATE SPUD: 8/18/94

CLIENT: AFCEE   RIG TYPE: CPT   DATE CMPL.: 8/18/94

JOB NO.: 722450.10   DRLG METHOD: CPT   ELEVATION: 919.21 ft msl

LOCATION: BATTLE CREEK ANG   BORING DIA.: 1.77"   TEMP: 70 F

GEOLOGIST: TH/SH   DRLG FLUID: NONE   WEATHER: Sunny

COMMENTS: Inpenetrable layer of cobbel and gravel encountered at 23 feet below ground surface

Elev (ft)	Depth (ft)	Profile	USCS	Geologic Description	Sample No.	Sample Depth (ft)	Sample Type	Penet Res	PID(ppm)	TLV(ppm)	TOTAL BTEX(ppm)	TPH (ppm)
	1–5		SP	Poorly sorted SAND with gravel		2–2.5	G					
	10–15		SP	Fine to medium poorly sorted SAND		14–14.5	G					
	20		SP	Fine to medium poorly sorted SAND		21–21.5	G					
	25–35											

Penet Res column: NOT MEASURED

NOTES
bgs – Below Ground Surface
GS – Ground Surface
TOC – Top of Casing
NS – Not Sampled
SAA – Same As Above

SAMPLE TYPE
D – DRIVE
C – CORE
G – GRAB

▼ Water level drilled

CONE PENETROMETER LOG

Site 3 (Fire Training Area)
Intrinsic Remediation RAP
Michigan Air National Guard, W.K. Kellogg Airport
Battle Creek, Michigan

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

CONE PENETROMETER LOG

Sheet 1 of 1

BORING NO.: ESSB-3   CONTRACTOR: USACE   DATE SPUD: 8/18/94
CLIENT: AFCEE   RIG TYPE: CPT   DATE CMPL.: 8/18/94
JOB NO.: 722450.10   DRLG METHOD: CPT   ELEVATION: 919.22 ft msl
LOCATION: BATTLE CREEK ANG   BORING DIA.: 1.77"   TEMP: 80 F
GEOLOGIST: TH/SH   DRLG FLUID: NONE   WEATHER: Sunny
COMMENTS:

Elev (ft)	Depth (ft)	Pro-file	USCS	Geologic Description	Sample No.	Sample Depth (ft)	Sample Type	Penet Res	PID(ppm)	TLV(ppm)	TOTAL BTEX(ppm)	TPH (ppm)
	1		SP	Fine to medium poorly sorted SAND Occurence of small pebbles		2-2.5	G					
	5							N				
	10							O				
	15		SP	Fine to medium poorly sorted SAND		14-14.5	G	T				
	20							M E A S U R E D				
			SM	Poorly sorted SAND with gravel Thin clay stringers		22-22.5	G		393			
	25											
	30											
	35											

NOTES

bgs – Below Ground Surface
GS – Ground Surface
TOC – Top of Casing
NS – Not Sampled
SAA – Same As Above

SAMPLE TYPE

D – DRIVE
C – CORE
G – GRAB

▼ Water level drilled

CONE PENETROMETER LOG

Site 3 (Fire Training Area)
Intrinsic Remediation RAP
Michigan Air National Guard, W.K. Kellogg Airport
Battle Creek, Michigan

PARSONS ENGINEERING SCIENCE, INC.

Denver, Colorado

CONE PENETROMETER LOG

BORING NO.: ESSB-7   CONTRACTOR: USACE   DATE SPUD: 8/18/94
CLIENT: AFCEE   RIG TYPE: CPT   DATE CMPL.: 8/18/94
JOB NO.: 722450.10   DRLG METHOD: Hoggen Toggler   ELEVATION: 921.82 ft msl
LOCATION: BATTLE CREEK ANG   BORING DIA.: 1.77"   TEMP: 70 F
GEOLOGIST: TH/SH   DRLG FLUID: NONE   WEATHER: Sunny
COMMENTS: Soil bore taken for background sample

Elev (ft)	Depth (ft)	Pro-file	US CS	Geologic Description	Sample No.	Sample Depth (ft)	Sample Type	Penet Res	PID(ppm)	TLV(ppm)	TOTAL BTEX(ppm)	TPH (ppm)
	1											
	5											
	10		SP	Fine to medium poorly sorted SAND Occurence of pebbles		10–10.5	G	N O T M E A S U R E D				
	15											
	20											
	25											
	30											
	35											

NOTES
bgs — Below Ground Surface
GS — Ground Surface
TOC — Top of Casing
NS — Not Sampled
SAA — Same As Above

SAMPLE TYPE
D — DRIVE
C — CORE
G — GRAB

▽ Water level drilled

CONE PENETROMETER LOG

Site 3 (Fire Training Area)
Intrinsic Remediation RAP
Michigan Air National Guard, W.K. Kellogg Airport
Battle Creek, Michigan

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

CONE PENETROMETER LOG

BORING NO.: ESSB-8   CONTRACTOR: USACE   DATE SPUD: 8/18/94
CLIENT: AFCEE   RIG TYPE: CPT   DATE CMPL.: 8/18/94
JOB NO.: 722450.10   DRLG METHOD: Hoggen Toggler   ELEVATION: 920.95 ft msl
LOCATION: BATTLE CREEK ANG   BORING DIA.: 1.77"   TEMP: 70 F
GEOLOGIST: TH/SH   DRLG FLUID: NONE   WEATHER: Sunny
COMMENTS: Soil bore taken for background sample

Elev (ft)	Depth (ft)	Pro-file	US CS	Geologic Description	Sample No.	Sample Depth (ft)	Sample Type	Penet Res	PID(ppm)	TLV(ppm)	TOTAL BTEX(ppm)	TPH (ppm)
	1											
	5											
	10	�	SP	Fine to medium poorly sorted SAND Occurence of pebbles		10–10.5	G	N O T M E A S U R E D				
	15											
	20											
	25											
	30											
	35											

NOTES

bgs – Below Ground Surface
GS – Ground Surface
TOC – Top of Casing
NS – Not Sampled
SAA – Same As Above

SAMPLE TYPE

D – DRIVE
C – CORE
G – GRAB

▼ Water level drilled

CONE PENETROMETER LOG

Site 3 (Fire Training Area)
Intrinsic Remediation RAP
Michigan Air National Guard, W.K. Kellogg Airport
Battle Creek, Michigan

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

CONE PENETROMETER LOG

BORING NO.: ESSB-10   CONTRACTOR: USACE   DATE SPUD: 8/21/94

CLIENT: AFCEE   RIG TYPE: CPT   DATE CMPL.: 8/21/94

JOB NO.: 722450.10   DRLG METHOD: Hoggen Toggler   ELEVATION: 912.50 ft msl

LOCATION: BATTLE CREEK ANG   BORING DIA.: 1.77"   TEMP: 70 F

GEOLOGIST: TH/SH   DRLG FLUID: NONE   WEATHER: Sunny

COMMENTS: Soil bore taken for background sample and cross gradient to the fire-training pit

Elev (ft)	Depth (ft)	Profile	USCS	Geologic Description	Sample No.	Sample Depth (ft)	Sample Type	Penet Res	PID (ppm)	TLV (ppm)	TOTAL BTEX (ppm)	TPH (ppm)
	5		SP	Fine to medium poorly sorted SAND Slight reddish color		5–5.5	G	N O T M E A S U R E D				
	18.5–20		SP	Fine to medium poorly sorted SAND No reddish color as above		18.5–19	G					

NOTES

bgs — Below Ground Surface
GS — Ground Surface
TOC — Top of Casing
NS — Not Sampled
SAA — Same As Above

SAMPLE TYPE

D — DRIVE
C — CORE
G — GRAB

▼ Water level drilled

CONE PENETROMETER LOG

Site 3 (Fire Training Area)
Intrinsic Remediation RAP
Michigan Air National Guard, W.K. Kellogg Airport
Battle Creek, Michigan

PARSONS ENGINEERING SCIENCE, INC.

Denver, Colorado

CONE PENETROMETER LOG

BORING NO.: ESSB-9 CONTRACTOR: USACE DATE SPUD: 8/18/94
CLIENT: AFCEE RIG TYPE: CPT DATE CMPL.: 8/18/94
JOB NO.: 722450.10 DRLG METHOD: Hoggen Toggler ELEVATION: 920.91 ft msl
LOCATION: BATTLE CREEK ANG BORING DIA.: 1.77" TEMP: 70 F
GEOLOGIST: TH/SH DRLG FLUID: NONE WEATHER: Sunny
COMMENTS: Soil bore taken for background sample

Elev (ft)	Depth (ft)	Pro-file	USCS	Geologic Description	Sample No.	Sample Depth (ft)	Sample Type	Penet Res	PID(ppm)	TLV(ppm)	TOTAL BTEX(ppm)	TPH (ppm)
	1											
	5							N				
	10	▓	SP	Fine to medium poorly sorted SAND Occurence of pebbles		10–10.5	G	O T				
	15							M				
	20							E A S U R E D				
	25												
	30												
	35												

NOTES

bgs – Below Ground Surface
GS – Ground Surface
TOC – Top of Casing
NS – Not Sampled
SAA – Same As Above

SAMPLE TYPE

D – DRIVE
C – CORE
G – GRAB

▼ Water level drilled

CONE PENETROMETER LOG

Site 3 (Fire Training Area)
Intrinsic Remediation RAP
Michigan Air National Guard, W.K. Kellogg Airport
Battle Creek, Michigan

PARSONS ENGINEERING SCIENCE, INC.

Denver, Colorado

MONITORING POINT INSTALLATION RECORD

JOB NAME __BATTLE CREEK ANGB__   MONITORING POINT NUMBER __ESMP-13S__
JOB NUMBER __722450.10__   INSTALLATION DATE __8/21/94__   LOCATION __SITE 3 (FIRE TRAINING AREA)__
DATUM ELEVATION __918.72 FT. MSL__   GROUND SURFACE ELEVATION _____
DATUM FOR WATER LEVEL MEASUREMENT __TOP OF CASING__
SCREEN DIAMETER & MATERIAL __1/2" ID, 3/4" OD PVC__   SLOT SIZE __0.01"__
RISER DIAMETER & MATERIAL __1/2" ID, 3/4" OD PVC__   BOREHOLE DIAMETER __1.4" O.D.__
CONE PENETROMETER CONTRACTOR __US ARMY CORP OF ENGINEERS__ ES REPRESENTATIVE __T.H.__

VENTED CAP
COVER
GROUND SURFACE
CONCRETE
THREADED COUPLING
LENGTH OF SOLID RISER: __30.14'__
SOLID RISER
TOTAL DEPTH OF MONITORING POINT: __30.59__ BTOC
LENGTH OF SCREEN: __3.28'__
SCREEN SLOT SIZE: __0.01"__
SCREEN
CAP

WELL REMOVED FROM GROUND

(NOT TO SCALE)

MEASUREMENT DATE: 8/21/94
STABILIZED WATER LEVEL __27.16__ FEET BELOW DATUM.
TOTAL MONITORING POINT DEPTH __30.59__ FEET BELOW DATUM.
GROUND SURFACE _____ FEET MSL

MONITORING POINT INSTALLATION RECORD

Site 3 (Fire Training Area)
Intrinsic Remediation RAP
Michigan Air National Guard, W.K. Kellogg Airport
Battle Creek, Michigan

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

M:\45010\DRAWINGS\ESMP-13S, 1/16/95 at 10:00

MONITORING POINT INSTALLATION RECORD

JOB NAME __BATTLE CREEK ANGB__   MONITORING POINT NUMBER __ESMP–1S__

JOB NUMBER __722450.10__   INSTALLATION DATE __8/19/94__   LOCATION __SITE 3 (FIRE TRAINING AREA)__

DATUM ELEVATION __919.1 FT MSL__   GROUND SURFACE ELEVATION _____

DATUM FOR WATER LEVEL MEASUREMENT __TOP OF CASING__

SCREEN DIAMETER & MATERIAL __1/2" ID, 3/4" OD PVC__   SLOT SIZE __0.01"__

RISER DIAMETER & MATERIAL __1/2" ID, 3/4" OD PVC__   BOREHOLE DIAMETER __1.4"__

CONE PENETROMETER CONTRACTOR __US ARMY CORP OF ENGINEERS__ ES REPRESENTATIVE __T.H.__

VENTED CAP

COVER

GROUND SURFACE

CONCRETE

THREADED COUPLING

LENGTH OF SOLID RISER: 27.88'

SOLID RISER

TOTAL DEPTH OF MONITORING POINT: 31.16 BTOC

LENGTH OF SCREEN: 3.28'

SCREEN SLOT SIZE: 0.01"

SCREEN

CAP

(NOT TO SCALE)

MEASUREMENT DATE: 8/23/94

STABILIZED WATER LEVEL __26.99__ FEET BELOW DATUM.

TOTAL MONITORING POINT DEPTH __31.16__ FEET BELOW DATUM.

GROUND SURFACE _____ FEET MSL

MONITORING POINT INSTALLATION RECORD

Site 3 (Fire Training Area)
Intrinsic Remediation RAP
Michigan Air National Guard, W.K. Kellogg Airport
Battle Creek, Michigan

PARSONS ENGINEERING SCIENCE, INC.

Denver, Colorado

MONITORING POINT INSTALLATION RECORD

JOB NAME __BATTLE CREEK ANGB__   MONITORING POINT NUMBER __ESMP-2S__

JOB NUMBER __722450.10__ INSTALLATION DATE __8/19/94__ LOCATION __SITE 3 (FIRE TRAINING AREA)__

DATUM ELEVATION __918.54 FT MSL__   GROUND SURFACE ELEVATION _____

DATUM FOR WATER LEVEL MEASUREMENT __TOP OF CASING__

SCREEN DIAMETER & MATERIAL __1/2" ID, 3/4" OD PVC__   SLOT SIZE __0.01"__

RISER DIAMETER & MATERIAL __1/2" ID, 3/4" OD PVC__ BOREHOLE DIAMETER __1.4"__

CONE PENETROMETER CONTRACTOR __US ARMY CORP OF ENGINEERS__ ES REPRESENTATIVE __T.H.__

VENTED CAP
COVER
GROUND SURFACE
CONCRETE
THREADED COUPLING
LENGTH OF SOLID RISER: __29.92'__
SOLID RISER
TOTAL DEPTH OF MONITORING POINT: __33.2'__ BTOC
LENGTH OF SCREEN: __3.28'__
SCREEN SLOT SIZE: __0.01"__
SCREEN
CAP

(NOT TO SCALE)

MEASUREMENT DATE: 8/23/94

STABILIZED WATER LEVEL __26.56__ FEET BELOW DATUM.

TOTAL MONITORING POINT DEPTH __33.2__ FEET BELOW DATUM.

GROUND SURFACE _____ FEET MSL

MONITORING POINT INSTALLATION RECORD

Site 3 (Fire Training Area)
Intrinsic Remediation RAP
Michigan Air National Guard, W.K. Kellogg Airport
Battle Creek, Michigan

PARSONS ENGINEERING SCIENCE, INC.

Denver, Colorado

M:\45010\DRAWINGS\ESMP-2S, 1/16/95 at 12:55

MONITORING POINT INSTALLATION RECORD

JOB NAME __BATTLE CREEK ANGB__ MONITORING POINT NUMBER __ESMP-2D__
JOB NUMBER __722450.10__ INSTALLATION DATE __8/19/94__ LOCATION __SITE 3 (FIRE TRAINING AREA)__
DATUM ELEVATION __918.48 FT. MSL__ GROUND SURFACE ELEVATION ____
DATUM FOR WATER LEVEL MEASUREMENT __TOP OF CASING__
SCREEN DIAMETER & MATERIAL __1/2" ID, 3/4" OD PVC__ SLOT SIZE __0.01"__
RISER DIAMETER & MATERIAL __1/2" ID, 3/4" OD PVC__ BOREHOLE DIAMETER __1.4" O.D.__
CONE PENETROMETER CONTRACTOR __US ARMY CORP OF ENGINEERS__ ES REPRESENTATIVE __T.H.__

VENTED CAP
COVER
GROUND SURFACE
CONCRETE
THREADED COUPLING
LENGTH OF SOLID RISER: __40.51'__
SOLID RISER
TOTAL DEPTH OF MONITORING POINT: __43.79'__ BTOC
LENGTH OF SCREEN: __3.28'__
SCREEN SLOT SIZE: __0.01"__
SCREEN
CAP

(NOT TO SCALE)

MEASUREMENT DATE: 8/23/94

STABILIZED WATER LEVEL __26.31__ FEET BELOW DATUM.

TOTAL MONITORING POINT DEPTH __43.79__ FEET BELOW DATUM.

GROUND SURFACE _____ FEET MSL

MONITORING POINT INSTALLATION RECORD

Site 3 (Fire Training Area)
Intrinsic Remediation RAP
Michigan Air National Guard, W.K. Kellogg Airport
Battle Creek, Michigan

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

M:\45010\DRAWINGS\ESMP-2D, 1/16/95 at 12:45

MONITORING POINT INSTALLATION RECORD

JOB NAME ___BATTLE CREEK ANGB___ MONITORING POINT NUMBER ___ESMP-3S___

JOB NUMBER ___722450.10___ INSTALLATION DATE ___8/19/94___ LOCATION _SITE 3 (FIRE TRAINING AREA)_

DATUM ELEVATION ___918.2 FT. MSL___ GROUND SURFACE ELEVATION _____

DATUM FOR WATER LEVEL MEASUREMENT ___TOP OF CASING___

SCREEN DIAMETER & MATERIAL ___1/2" ID, 3/4" OD PVC___ SLOT SIZE ___0.01" FT___

RISER DIAMETER & MATERIAL ___1/2" ID, 3/4" OD PVC___ BOREHOLE DIAMETER ___1.4" O.D.___

CONE PENETROMETER CONTRACTOR _US ARMY CORP OF ENGINEERS_ ES REPRESENTATIVE ___T.H.___

VENTED CAP

COVER

GROUND SURFACE

CONCRETE

THREADED COUPLING

SOLID RISER

SCREEN

CAP

LENGTH OF SOLID RISER: 27.12'

LENGTH OF SCREEN: 3.28'

SCREEN SLOT SIZE: 0.01"

TOTAL DEPTH OF MONITORING POINT: 30.4' BTOC

(NOT TO SCALE)

MEASUREMENT DATE: 8/23/94

STABILIZED WATER LEVEL __26.51__ FEET BELOW DATUM.

TOTAL MONITORING POINT DEPTH __30.4__ FEET BELOW DATUM.

GROUND SURFACE _____ FEET MSL

MONITORING POINT INSTALLATION RECORD

Site 3 (Fire Training Area)
Intrinsic Remediation RAP
Michigan Air National Guard, W.K. Kellogg Airport
Battle Creek, Michigan

PARSONS ENGINEERING SCIENCE, INC.

Denver, Colorado

M:\45010\DRAWINGS\ESMP-3S, 1/16/95 at 12:40

MONITORING POINT INSTALLATION RECORD

JOB NAME __BATTLE CREEK ANGB__   MONITORING POINT NUMBER __ESMP-3D__

JOB NUMBER __722450.10__   INSTALLATION DATE __8/19/94__   LOCATION __SITE 3 (FIRE TRAINING AREA)__

DATUM ELEVATION __918.24 FT. MSL__   GROUND SURFACE ELEVATION _____

DATUM FOR WATER LEVEL MEASUREMENT __TOP OF CASING__

SCREEN DIAMETER & MATERIAL __1/2" ID, 3/4" OD PVC__   SLOT SIZE __0.01"__

RISER DIAMETER & MATERIAL __1/2" ID, 3/4" OD PVC__   BOREHOLE DIAMETER __1.4" O.D.__

CONE PENETROMETER CONTRACTOR __US ARMY CORP OF ENGINEERS__ ES REPRESENTATIVE __T.H.__

VENTED CAP

COVER

GROUND SURFACE

CONCRETE

THREADED COUPLING

LENGTH OF SOLID RISER: __39.98'__

SOLID RISER

TOTAL DEPTH OF MONITORING POINT: __43.26'__ BTOC

LENGTH OF SCREEN: __3.28'__

SCREEN SLOT SIZE: __0.01"__

SCREEN

CAP

(NOT TO SCALE)

MEASUREMENT DATE: 8/23/94

STABILIZED WATER LEVEL __26.61__ FEET BELOW DATUM.

TOTAL MONITORING POINT DEPTH __43.26__ FEET BELOW DATUM.

GROUND SURFACE _____ FEET MSL

MONITORING POINT INSTALLATION RECORD

Site 3 (Fire Training Area)
Intrinsic Remediation RAP
Michigan Air National Guard, W.K. Kellogg Airport
Battle Creek, Michigan

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

MONITORING POINT INSTALLATION RECORD

JOB NAME __BATTLE CREEK ANGB__   MONITORING POINT NUMBER __ESMP-3DD__

JOB NUMBER __722450.10__   INSTALLATION DATE __8/20/94__   LOCATION __SITE 3 (FIRE TRAINING AREA)__

DATUM ELEVATION __918.14 FT. MSL__   GROUND SURFACE ELEVATION _____

DATUM FOR WATER LEVEL MEASUREMENT __TOP OF CASING__

SCREEN DIAMETER & MATERIAL __1/2" ID, 3/4" OD PVC__   SLOT SIZE __0.01"__

RISER DIAMETER & MATERIAL __1/2" ID, 3/4" OD PVC__   BOREHOLE DIAMETER __1.4" O.D.__

CONE PENETROMETER CONTRACTOR __US ARMY CORP OF ENGINEERS__ ES REPRESENTATIVE __T.H.__

VENTED CAP

COVER

GROUND SURFACE

CONCRETE

THREADED COUPLING

LENGTH OF SOLID RISER: __53.01'__

SOLID RISER

TOTAL DEPTH OF MONITORING POINT: __56.29'__ BTOC

LENGTH OF SCREEN: __3.28'__

SCREEN SLOT SIZE: __0.01"__

SCREEN

CAP

(NOT TO SCALE)

MEASUREMENT DATE: 8/23/94

STABILIZED WATER LEVEL __26.78__ FEET BELOW DATUM.

TOTAL MONITORING POINT DEPTH __56.29__ FEET BELOW DATUM.

GROUND SURFACE _____ FEET MSL

MONITORING POINT INSTALLATION RECORD

Site 3 (Fire Training Area)
Intrinsic Remediation RAP
Michigan Air National Guard, W.K. Kellogg Airport
Battle Creek, Michigan

PARSONS ENGINEERING SCIENCE, INC.

Denver, Colorado

M:\45010\DRAWINGS\ESMP-3DD, 1/16/95 at 12:30

MONITORING POINT INSTALLATION RECORD

JOB NAME ___BATTLE CREEK ANGB___   MONITORING POINT NUMBER ___ESMP-4S___
JOB NUMBER ___722450.10___ INSTALLATION DATE ___8/19/94___ LOCATION __SITE 3 (FIRE TRAINING AREA)__
DATUM ELEVATION ___916.95 FT. MSL___   GROUND SURFACE ELEVATION ___917.21 ft MSL___
DATUM FOR WATER LEVEL MEASUREMENT ___TOP OF CASING___
SCREEN DIAMETER & MATERIAL ___1/2" ID, 3/4" OD PVC___   SLOT SIZE ___0.01"___
RISER DIAMETER & MATERIAL ___1/2" ID, 3/4" OD PVC___   BOREHOLE DIAMETER ___1.4" O.D.___
CONE PENETROMETER CONTRACTOR __US ARMY CORP OF ENGINEERS__ ES REPRESENTATIVE ___T.H.___

VENTED CAP
COVER
GROUND SURFACE
CONCRETE
THREADED COUPLING
LENGTH OF SOLID RISER: ___26.56'___
SOLID RISER
TOTAL DEPTH OF MONITORING POINT: ___29.84'___ BTOC
LENGTH OF SCREEN: ___3.28'___
SCREEN SLOT SIZE: ___0.01"___
SCREEN
CAP

(NOT TO SCALE)

MEASUREMENT DATE: 8/23/94

STABILIZED WATER LEVEL ___25.50___ FEET BELOW DATUM.

TOTAL MONITORING POINT DEPTH ___29.84___ FEET BELOW DATUM.

GROUND SURFACE ___917.21___ FEET MSL

**MONITORING POINT
INSTALLATION RECORD**

Site 3 (Fire Training Area)
Intrinsic Remediation RAP
Michigan Air National Guard, W.K. Kellogg Airport
Battle Creek, Michigan

**PARSONS
ENGINEERING SCIENCE, INC.**
Denver, Colorado

M:\45010\DRAWINGS\ESMP-4S, 1/16/95 at 12:20

MONITORING POINT INSTALLATION RECORD

JOB NAME ___BATTLE CREEK ANGB___ MONITORING POINT NUMBER ___ESMP-4D___

JOB NUMBER ___722450.10___ INSTALLATION DATE ___8/20/94___ LOCATION ___SITE 3 (FIRE TRAINING AREA)___

DATUM ELEVATION ___916.83 FT. MSL___ GROUND SURFACE ELEVATION _____

DATUM FOR WATER LEVEL MEASUREMENT ___TOP OF CASING___

SCREEN DIAMETER & MATERIAL ___1/2" ID, 3/4" OD PVC___ SLOT SIZE ___0.01"___

RISER DIAMETER & MATERIAL ___1/2" ID, 3/4" OD PVC___ BOREHOLE DIAMETER ___1.4" O.D.___

CONE PENETROMETER CONTRACTOR ___US ARMY CORP OF ENGINEERS___ ES REPRESENTATIVE ___T.H.___

VENTED CAP
COVER
GROUND SURFACE
CONCRETE
THREADED COUPLING
SOLID RISER
SCREEN
CAP

LENGTH OF SOLID RISER: __39.62'__

TOTAL DEPTH OF MONITORING POINT: __42.9' BTOC__

LENGTH OF SCREEN: __3.28'__

SCREEN SLOT SIZE: __0.01"__

(NOT TO SCALE)

MEASUREMENT DATE: 8/23/94

STABILIZED WATER LEVEL __25.66__ FEET BELOW DATUM.

TOTAL MONITORING POINT DEPTH __42.9__ FEET BELOW DATUM.

GROUND SURFACE _____ FEET MSL

MONITORING POINT INSTALLATION RECORD

Site 3 (Fire Training Area)
Intrinsic Remediation RAP
Michigan Air National Guard, W.K. Kellogg Airport
Battle Creek, Michigan

PARSONS ENGINEERING SCIENCE, INC.

Denver, Colorado

MONITORING POINT INSTALLATION RECORD

JOB NAME __BATTLE CREEK ANGB__ MONITORING POINT NUMBER __ESMP-5S__

JOB NUMBER __722450.10__ INSTALLATION DATE __8/20/94__ LOCATION __SITE 3 (FIRE TRAINING AREA)__

DATUM ELEVATION __916.38 FT. MSL__ GROUND SURFACE ELEVATION _____

DATUM FOR WATER LEVEL MEASUREMENT __TOP OF CASING__

SCREEN DIAMETER & MATERIAL __1/2" ID, 3/4" OD PVC__ SLOT SIZE __0.01"__

RISER DIAMETER & MATERIAL __1/2" ID, 3/4" OD PVC__ BOREHOLE DIAMETER __1.4" O.D.__

CONE PENETROMETER CONTRACTOR __US ARMY CORP OF ENGINEERS__ ES REPRESENTATIVE __T.H.__

VENTED CAP
COVER
GROUND SURFACE
CONCRETE
THREADED COUPLING
LENGTH OF SOLID RISER: __22.9'__
SOLID RISER
TOTAL DEPTH OF MONITORING POINT: __26.18'__ MSL
LENGTH OF SCREEN: __3.28'__
SCREEN SLOT SIZE: __0.01"__
SCREEN
CAP.

(NOT TO SCALE)

MEAURMENT DATE: 8/23/94

STABILIZED WATER LEVEL __25.11__ FEET BELOW DATUM.

TOTAL MONITORING POINT DEPTH __26.18__ FEET BELOW DATUM.

GROUND SURFACE _____ FEET MSL

MONITORING POINT INSTALLATION RECORD

Site 3 (Fire Training Area)
Intrinsic Remediation RAP
Michigan Air National Guard, W.K. Kellogg Airport
Battle Creek, Michigan

PARSONS ENGINEERING SCIENCE, INC.

Denver, Colorado

M:\45010\DRAWINGS\ESMP-5S, 1/16/95 at 11:55

MONITORING POINT INSTALLATION RECORD

JOB NAME __BATTLE CREEK ANGB__ MONITORING POINT NUMBER __ESMP-5D__

JOB NUMBER __722450.10__ INSTALLATION DATE __8/20/94__ LOCATION __SITE 3 (FIRE TRAINING AREA)__

DATUM ELEVATION __916.39 FT. MSL__ GROUND SURFACE ELEVATION _____

DATUM FOR WATER LEVEL MEASUREMENT __TOP OF CASING__

SCREEN DIAMETER & MATERIAL __1/2" ID, 3/4" OD PVC__ SLOT SIZE __0.01"__

RISER DIAMETER & MATERIAL __1/2" ID, 3/4" OD PVC__ BOREHOLE DIAMETER __1.4" O.D.__

CONE PENETROMETER CONTRACTOR __US ARMY CORP OF ENGINEERS__ ES REPRESENTATIVE __T.H.__

VENTED CAP
COVER
GROUND SURFACE
CONCRETE
THREADED COUPLING
SOLID RISER

LENGTH OF SOLID RISER: __36.7'__

TOTAL DEPTH OF MONITORING POINT: __39.98'__ BTOC

LENGTH OF SCREEN: __3.28'__

SCREEN SLOT SIZE: __0.01"__

SCREEN
CAP

(NOT TO SCALE)

MEASUREMENT DATE: 8/23/94

STABILIZED WATER LEVEL __25.23__ FEET BELOW DATUM.

TOTAL MONITORING POINT DEPTH __39.98__ FEET BELOW DATUM.

GROUND SURFACE _____ FEET MSL

MONITORING POINT INSTALLATION RECORD

Site 3 (Fire Training Area)
Intrinsic Remediation RAP
Michigan Air National Guard, W.K. Kellogg Airport
Battle Creek, Michigan

PARSONS ENGINEERING SCIENCE, INC.

Denver, Colorado

M:\45010\DRAWINGS\ESMP-5D, 1/16/95 at 11:45

MONITORING POINT INSTALLATION RECORD

JOB NAME __BATTLE CREEK ANGB__ MONITORING POINT NUMBER __ESMP-6S__

JOB NUMBER __722450.10__ INSTALLATION DATE __8/20/94__ LOCATION __SITE 3 (FIRE TRAINING AREA)__

DATUM ELEVATION __915.39 FT. MSL__ GROUND SURFACE ELEVATION __915.65__ ft MSL

DATUM FOR WATER LEVEL MEASUREMENT __TOP OF CASING__

SCREEN DIAMETER & MATERIAL __1/2" ID, 3/4" OD PVC__ SLOT SIZE __0.01"__

RISER DIAMETER & MATERIAL __1/2" ID, 3/4" OD PVC__ BOREHOLE DIAMETER __1.4" O.D.__

CONE PENETROMETER CONTRACTOR __US ARMY CORP OF ENGINEERS__ ES REPRESENTATIVE __T.H.__

VENTED CAP
COVER
GROUND SURFACE
CONCRETE
THREADED COUPLING
SOLID RISER
SCREEN
CAP

LENGTH OF SOLID RISER: __23.15'__

TOTAL DEPTH OF MONITORING POINT: __26.43'__ BTOC

LENGTH OF SCREEN: __3.28'__

SCREEN SLOT SIZE: __0.01"__

(NOT TO SCALE)

MEASUREMENT DATE: 8/23/94

STABILIZED WATER LEVEL __24.62__ FEET BELOW DATUM.

TOTAL MONITORING POINT DEPTH __26.43__ FEET BELOW DATUM.

GROUND SURFACE _____ FEET MSL

MONITORING POINT INSTALLATION RECORD

Site 3 (Fire Training Area)
Intrinsic Remediation RAP
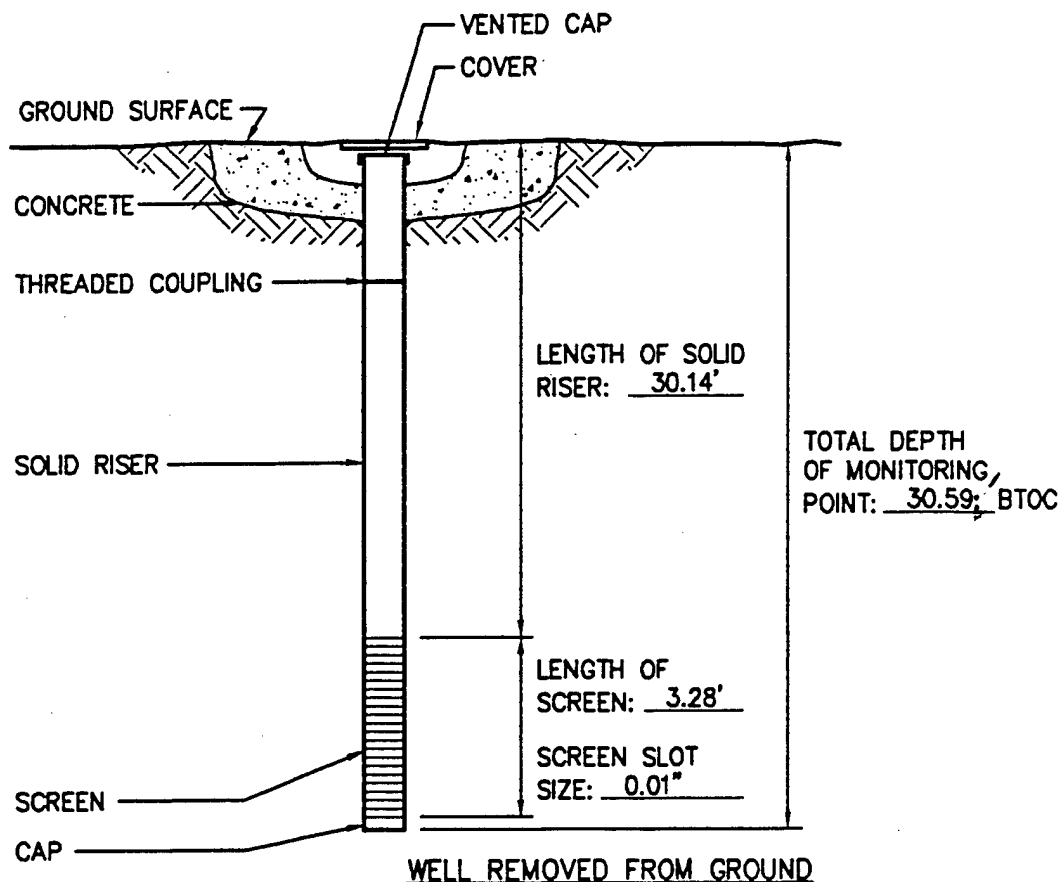Michigan Air National Guard, W.K. Kellogg Airport
Battle Creek, Michigan

PARSONS ENGINEERING SCIENCE, INC.

Denver, Colorado

M:\45010\DRAWINGS\ESMP-6S, 1/16/95 at 11:30

MONITORING POINT INSTALLATION RECORD

JOB NAME ___BATTLE CREEK ANGB___ MONITORING POINT NUMBER ___ESMP-6D___

JOB NUMBER ___722450.10___ INSTALLATION DATE ___08/20/94___ LOCATION ___SITE 3 (FIRE TRAINING AREA)___

DATUM ELEVATION ___915.31 FT. MSL___ GROUND SURFACE ELEVATION _____

DATUM FOR WATER LEVEL MEASUREMENT ___TOP OF CASING___

SCREEN DIAMETER & MATERIAL ___1/2" ID, 3/4" OD PVC___ SLOT SIZE ___0.01"___

RISER DIAMETER & MATERIAL ___1/2" ID, 3/4" OD PVC___ BOREHOLE DIAMETER ___1.4" O.D.___

CONE PENETROMETER CONTRACTOR ___US ARMY CORP OF ENGINEERS___ ES REPRESENTATIVE ___T.H.___

VENTED CAP
COVER
GROUND SURFACE
CONCRETE
THREADED COUPLING
SOLID RISER
SCREEN
CAP

LENGTH OF SOLID RISER: __36.72'__

TOTAL DEPTH OF MONITORING POINT: __40.0'__ BTOC

LENGTH OF SCREEN: __3.28'__

SCREEN SLOT SIZE: __0.01"__

(NOT TO SCALE)

MEASUREMENT DATE: 8/23/94

STABILIZED WATER LEVEL __24.67__ FEET BELOW DATUM.

TOTAL MONITORING POINT DEPTH __40.0__ FEET BELOW DATUM.

GROUND SURFACE _____ FEET MSL

MONITORING POINT INSTALLATION RECORD

Site 3 (Fire Training Area)
Intrinsic Remediation RAP
Michigan Air National Guard, W.K. Kellogg Airport
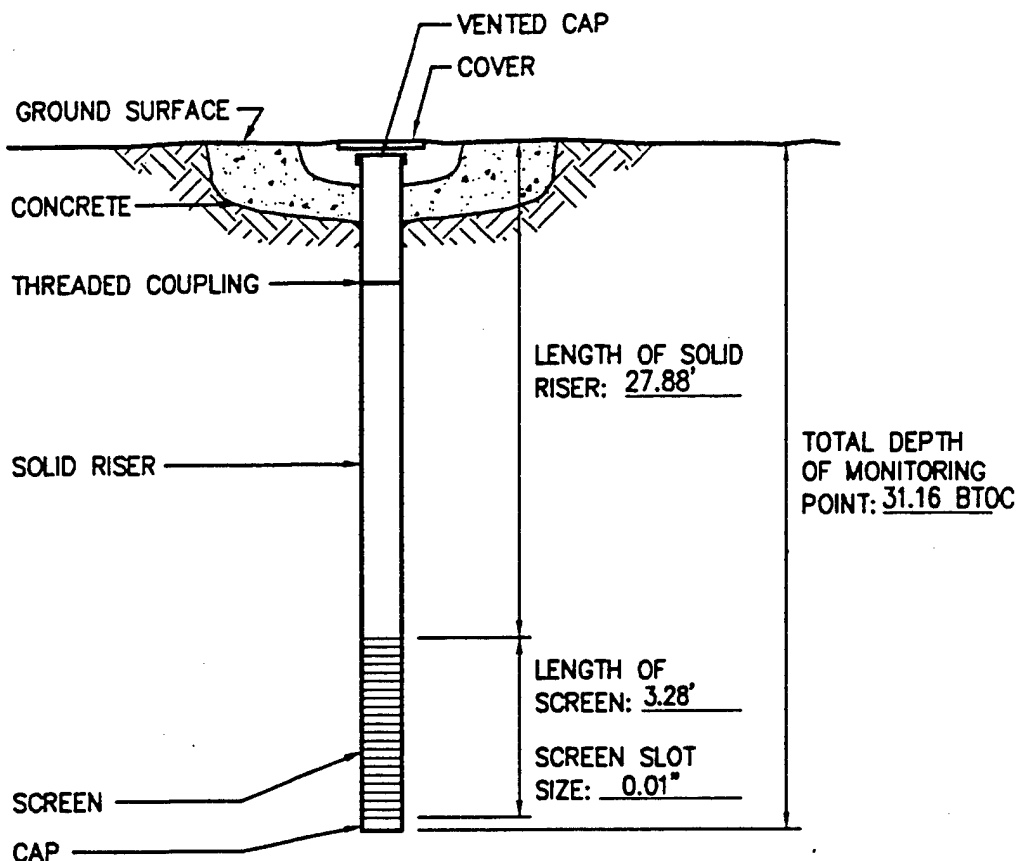Battle Creek, Michigan

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

M:\45010\DRAWINGS\ESMP-6D, 1/16/95 at 11:15

MONITORING POINT INSTALLATION RECORD

JOB NAME __BATTLE CREEK ANGB__ MONITORING POINT NUMBER __ESMW-7D__
JOB NUMBER __722450.10__ INSTALLATION DATE __8/20/94__ LOCATION __SITE 3 (FIRE TRAINING AREA)__
DATUM ELEVATION __917.18 FT. MSL__ GROUND SURFACE ELEVATION _____
DATUM FOR WATER LEVEL MEASUREMENT __TOP OF CASING__
SCREEN DIAMETER & MATERIAL __1/2" ID, 3/4" OD PVC__ SLOT SIZE __0.01"__
RISER DIAMETER & MATERIAL __1/2" ID, 3/4" OD PVC__ BOREHOLE DIAMETER __1.4" O.D.__
CONE PENETROMETER CONTRACTOR __US ARMY CORP OF ENGINEERS__ ES REPRESENTATIVE __T.H.__

VENTED CAP
COVER
GROUND SURFACE
CONCRETE
THREADED COUPLING
SOLID RISER
SCREEN
CAP

LENGTH OF SOLID RISER: __37.24'__

TOTAL DEPTH OF MONITORING POINT: __40.52'__ BTOC

LENGTH OF SCREEN: __3.28'__

SCREEN SLOT SIZE: __0.01"__

(NOT TO SCALE)

MEASUREMENT DATE: 8/23/94

STABILIZED WATER LEVEL __25.57__ FEET BELOW DATUM.

TOTAL MONITORING POINT DEPTH __40.52__ FEET BELOW DATUM.

GROUND SURFACE _____ FEET MSL

MONITORING POINT INSTALLATION RECORD

Site 3 (Fire Training Area)
Intrinsic Remediation RAP
Michigan Air National Guard, W.K. Kellogg Airport
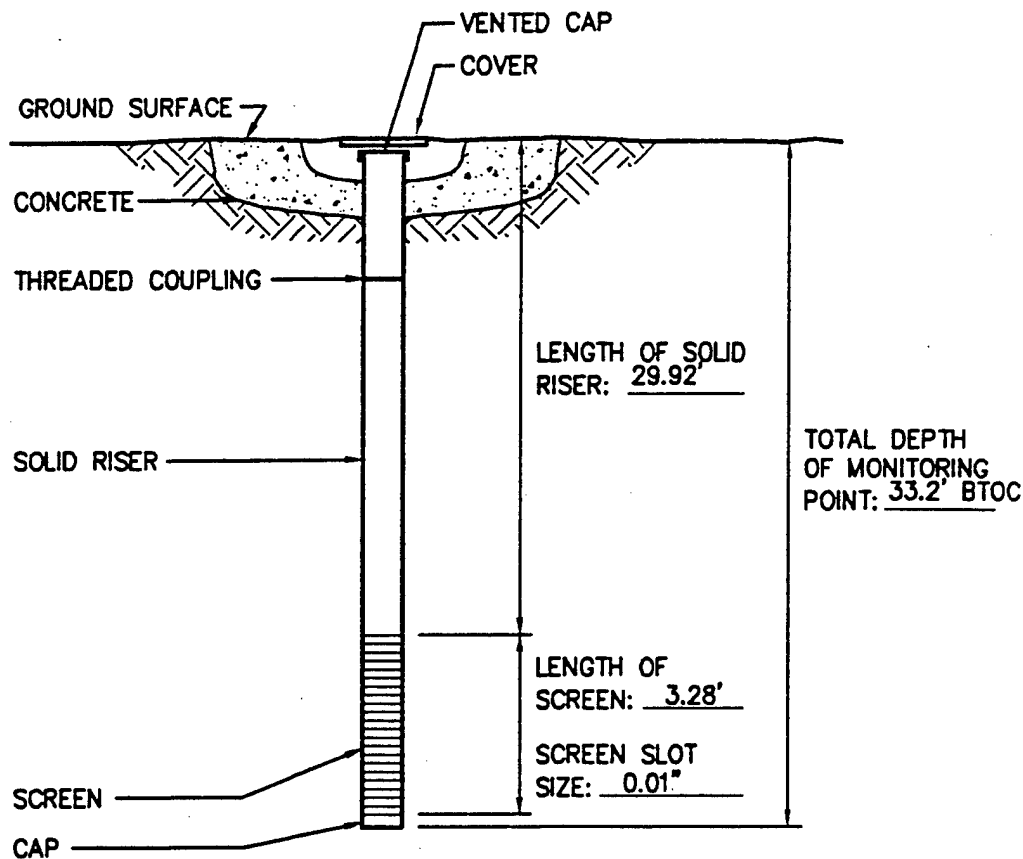Battle Creek, Michigan

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

M:\45010\DRAWINGS\ESMP-7D, 1/16/95 at 10:55

MONITORING POINT INSTALLATION RECORD

JOB NAME ___BATTLE CREEK ANGB___ MONITORING POINT NUMBER ___ESMW-7S___

JOB NUMBER ___722450.10___ INSTALLATION DATE ___8/20/94___ LOCATION SITE 3 (FIRE TRAINING AREA)

DATUM ELEVATION ___917.1 FT. MSL___ GROUND SURFACE ELEVATION ___917.43 FT. MSL___

DATUM FOR WATER LEVEL MEASUREMENT ___TOP OF CASING___

SCREEN DIAMETER & MATERIAL ___1/2" ID, 3/4" OD PVC___ SLOT SIZE ___0.01"___

RISER DIAMETER & MATERIAL ___1/2" ID, 3/4" OD PVC___ BOREHOLE DIAMETER ___1.4" O.D.___

CONE PENETROMETER CONTRACTOR US ARMY CORP OF ENGINEERS ES REPRESENTATIVE ___T.H.___

VENTED CAP
COVER
GROUND SURFACE
CONCRETE
THREADED COUPLING
LENGTH OF SOLID RISER: 25.31'
SOLID RISER
TOTAL DEPTH OF MONITORING POINT: 28.59' BTOC
LENGTH OF SCREEN: 3.28'
SCREEN SLOT SIZE: 0.01"
SCREEN
CAP

(NOT TO SCALE)

MEASUREMENT DATE: 8/23/94

STABILIZED WATER LEVEL ___25.53___ FEET BELOW DATUM.

TOTAL MONITORING POINT DEPTH ___28.59___ FEET BELOW DATUM.

GROUND SURFACE ___917.43___ FEET MSL

MONITORING POINT INSTALLATION RECORD

Site 3 (Fire Training Area)
Intrinsic Remediation RAP
Michigan Air National Guard, W.K. Kellogg Airport
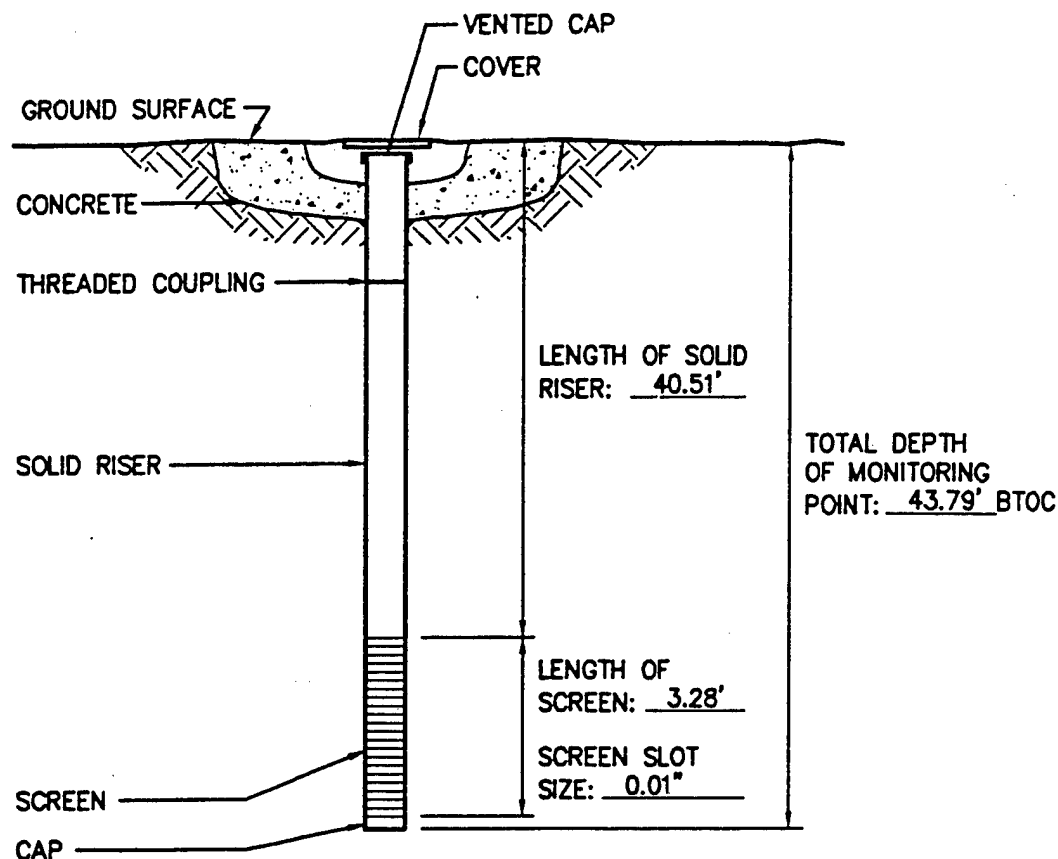Battle Creek, Michigan

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

M:\45010\DRAWINGS\ESMP-7S, 1/16/95 at 10:50

MONITORING POINT INSTALLATION RECORD

JOB NAME __BATTLE CREEK ANGB__   MONITORING POINT NUMBER __ESMP-8S__

JOB NUMBER __722450.10__   INSTALLATION DATE __8/20/94__   LOCATION __SITE 3 (FIRE TRAINING AREA)__

DATUM ELEVATION __921.11 FT. MSL__   GROUND SURFACE ELEVATION _____

DATUM FOR WATER LEVEL MEASUREMENT __TOP OF CASING__

SCREEN DIAMETER & MATERIAL __1/2" ID, 3/4" OD PVC__   SLOT SIZE __0.01"__

RISER DIAMETER & MATERIAL __1/2" ID, 3/4" OD PVC__   BOREHOLE DIAMETER __1.4" O.D.__

CONE PENETROMETER CONTRACTOR __US ARMY CORP OF ENGINEERS__   ES REPRESENTATIVE __T.H.__

VENTED CAP
COVER
GROUND SURFACE
CONCRETE
THREADED COUPLING
SOLID RISER
SCREEN
CAP

LENGTH OF SOLID RISER: __28.71'__

TOTAL DEPTH OF MONITORING POINT: __31.99'__ MSL

LENGTH OF SCREEN: __3.28'__

SCREEN SLOT SIZE: __0.01"__

(NOT TO SCALE)

MEASUREMENT DATE: 8/23/94

STABILIZED WATER LEVEL __28.43__ FEET BELOW DATUM.

TOTAL MONITORING POINT DEPTH __31.99__ FEET BELOW DATUM.

GROUND SURFACE _____ FEET MSL

MONITORING POINT INSTALLATION RECORD

Site 3 (Fire Training Area)
Intrinsic Remediation RAP
Michigan Air National Guard, W.K. Kellogg Airport
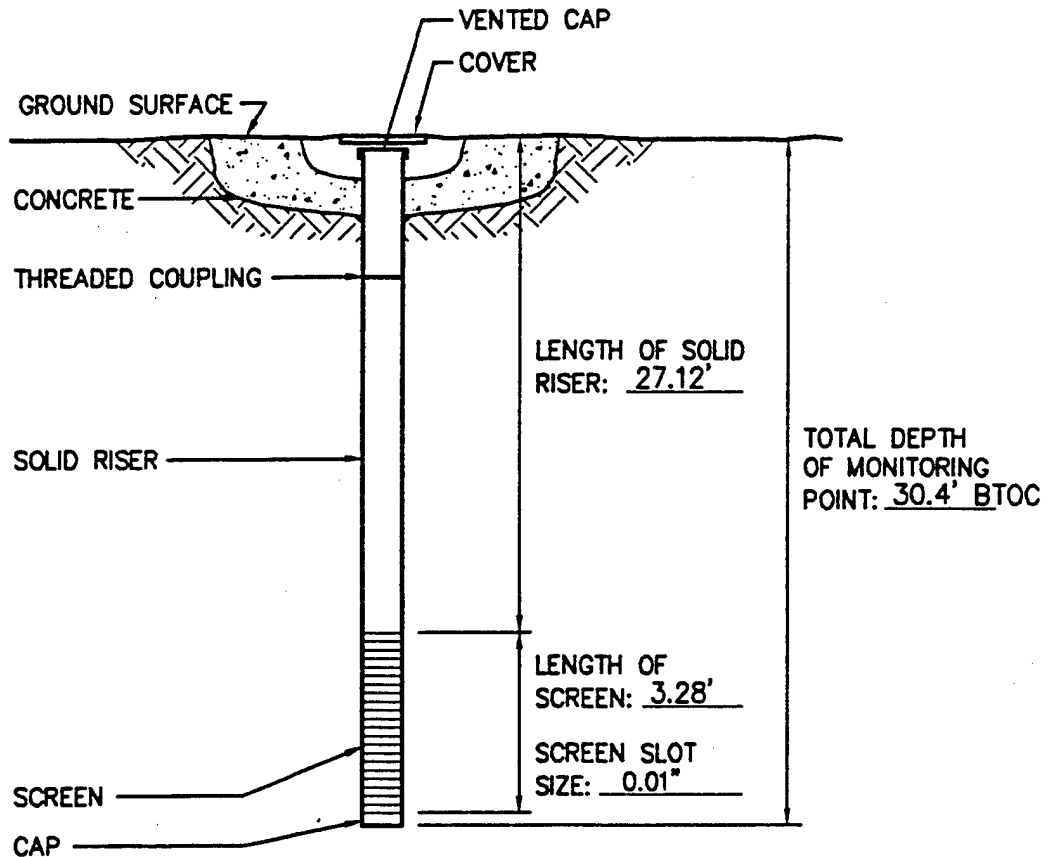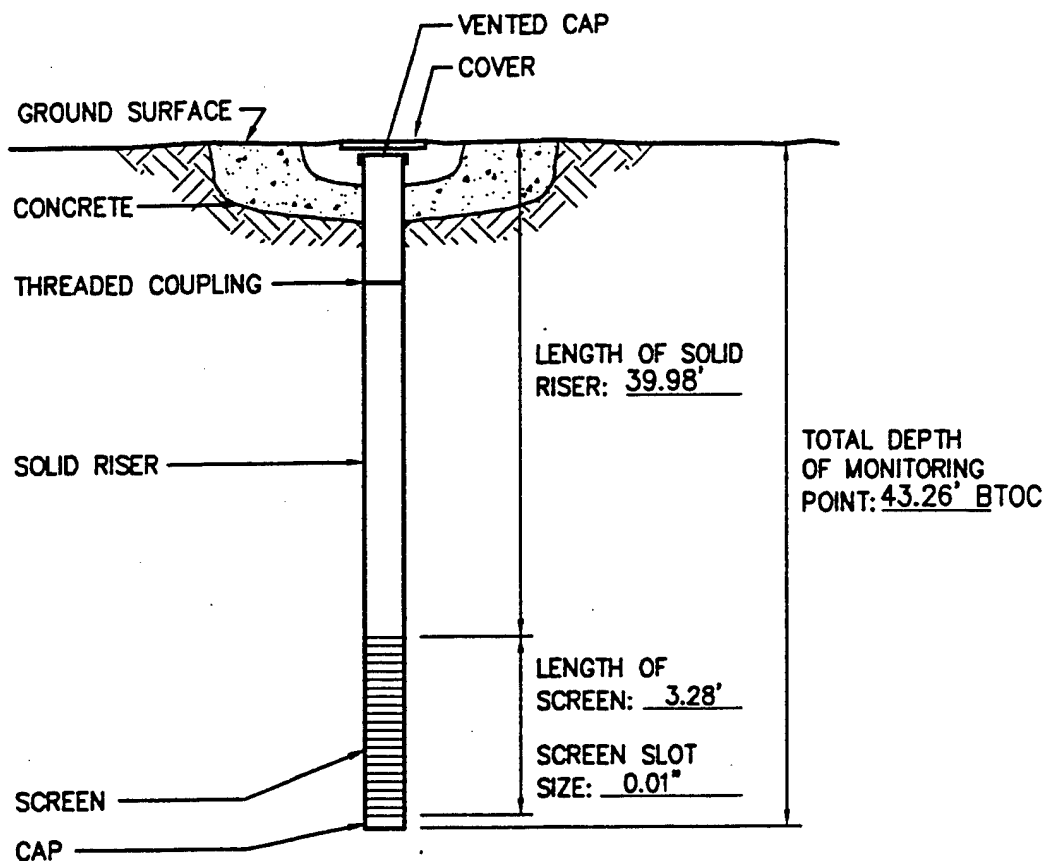Battle Creek, Michigan

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

M:\45010\DRAWINGS\ESMP-8S, 1/16/95 at 10:45

MONITORING POINT INSTALLATION RECORD

JOB NAME __BATTLE CREEK ANGB__   MONITORING POINT NUMBER __ESMP-8D__

JOB NUMBER __722450.10__   INSTALLATION DATE __8/20/94__   LOCATION __SITE 3 (FIRE TRAINING AREA)__

DATUM ELEVATION __920.98 FT. MSL__   GROUND SURFACE ELEVATION _____

DATUM FOR WATER LEVEL MEASUREMENT __TOP OF CASING__

SCREEN DIAMETER & MATERIAL __1/2" ID, 3/4" OD PVC__   SLOT SIZE __0.01"__

RISER DIAMETER & MATERIAL __1/2" ID, 3/4" OD PVC__   BOREHOLE DIAMETER __1.4" O.D.__

CONE PENETROMETER CONTRACTOR __US ARMY CORP OF ENGINEERS__ ES REPRESENTATIVE __T.H.__

VENTED CAP
COVER
GROUND SURFACE
CONCRETE
THREADED COUPLING
LENGTH OF SOLID RISER: __41.79'__
SOLID RISER
TOTAL DEPTH OF MONITORING POINT: __45.07'__ BTOC
LENGTH OF SCREEN: __3.28'__
SCREEN SLOT SIZE: __0.01"__
SCREEN
CAP
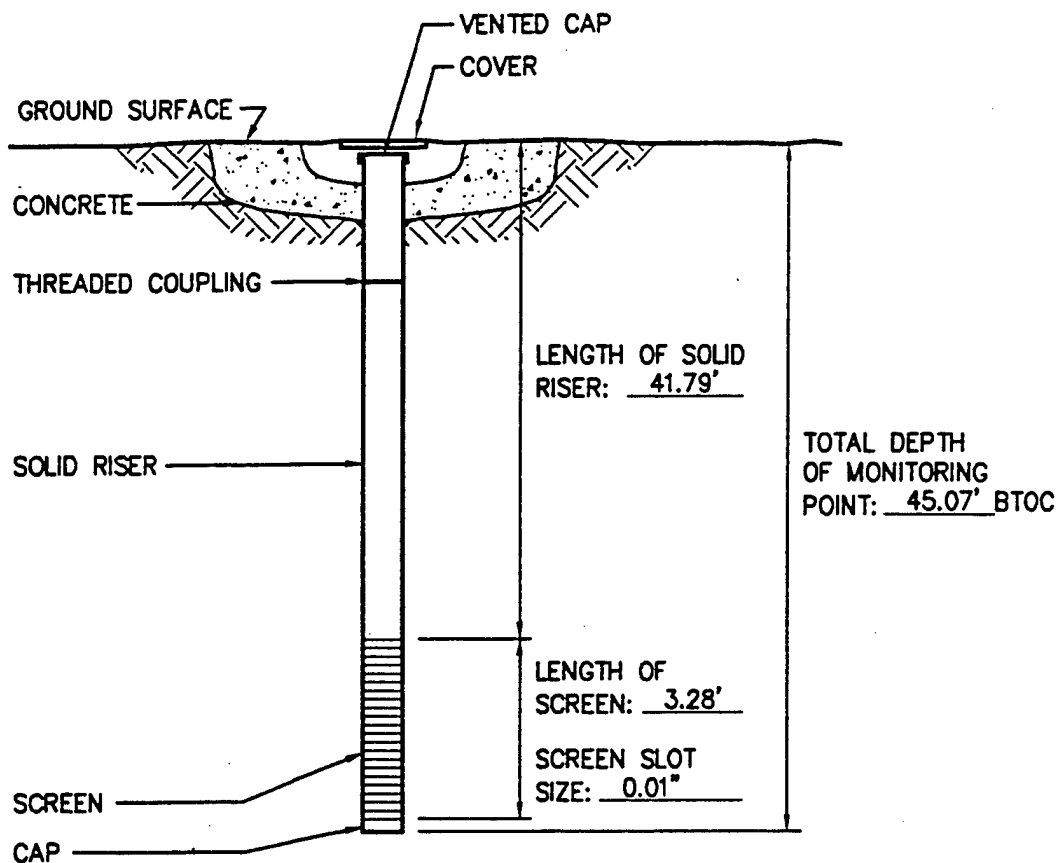
(NOT TO SCALE)

MEASUREMENT DATE: 8/23/94

STABILIZED WATER LEVEL __28.54__ FEET BELOW DATUM.

TOTAL MONITORING POINT DEPTH __45.07__ FEET BELOW DATUM.

GROUND SURFACE _____ FEET MSL

MONITORING POINT INSTALLATION RECORD

Site 3 (Fire Training Area)
Intrinsic Remediation RAP
Michigan Air National Guard, W.K. Kellogg Airport
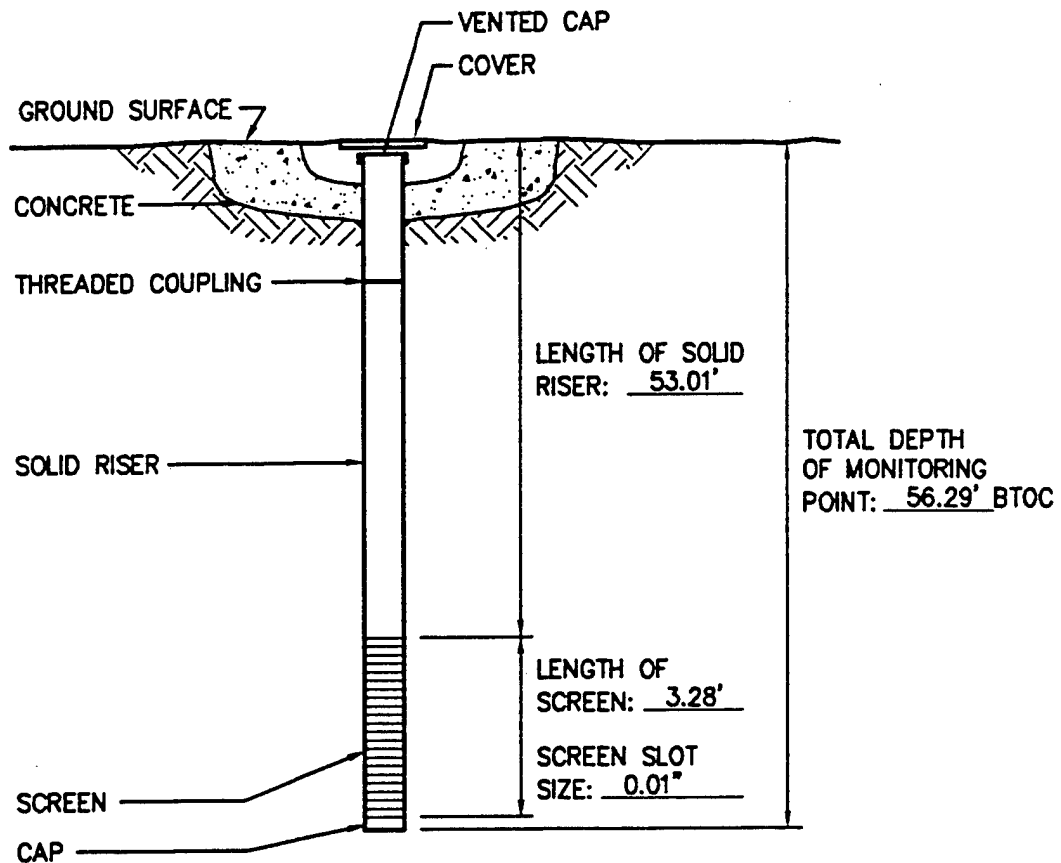Battle Creek, Michigan

PARSONS ENGINEERING SCIENCE, INC.

Denver, Colorado

MONITORING POINT INSTALLATION RECORD

JOB NAME __BATTLE CREEK ANGB__ MONITORING POINT NUMBER __ESMP-9S__

JOB NUMBER __722450.10__ INSTALLATION DATE __8/20/94__ LOCATION __SITE 3 (FIRE TRAINING AREA)__

DATUM ELEVATION __918.95 FT. MSL__ GROUND SURFACE ELEVATION _____

DATUM FOR WATER LEVEL MEASUREMENT __TOP OF CASING__

SCREEN DIAMETER & MATERIAL __1/2" ID, 3/4" OD PVC__ SLOT SIZE __0.01"__

RISER DIAMETER & MATERIAL __1/2" ID, 3/4" OD PVC__ BOREHOLE DIAMETER __1.4" O.D.__

CONE PENETROMETER CONTRACTOR __US ARMY CORP OF ENGINEERS__ ES REPRESENTATIVE __T.H.__

VENTED CAP
COVER
GROUND SURFACE
CONCRETE
THREADED COUPLING
LENGTH OF SOLID RISER: __24.84'__
SOLID RISER
TOTAL DEPTH OF MONITORING POINT: __28.12'__ MSL
LENGTH OF SCREEN: __3.28'__
SCREEN SLOT SIZE: __0.01"__
SCREEN
CAP
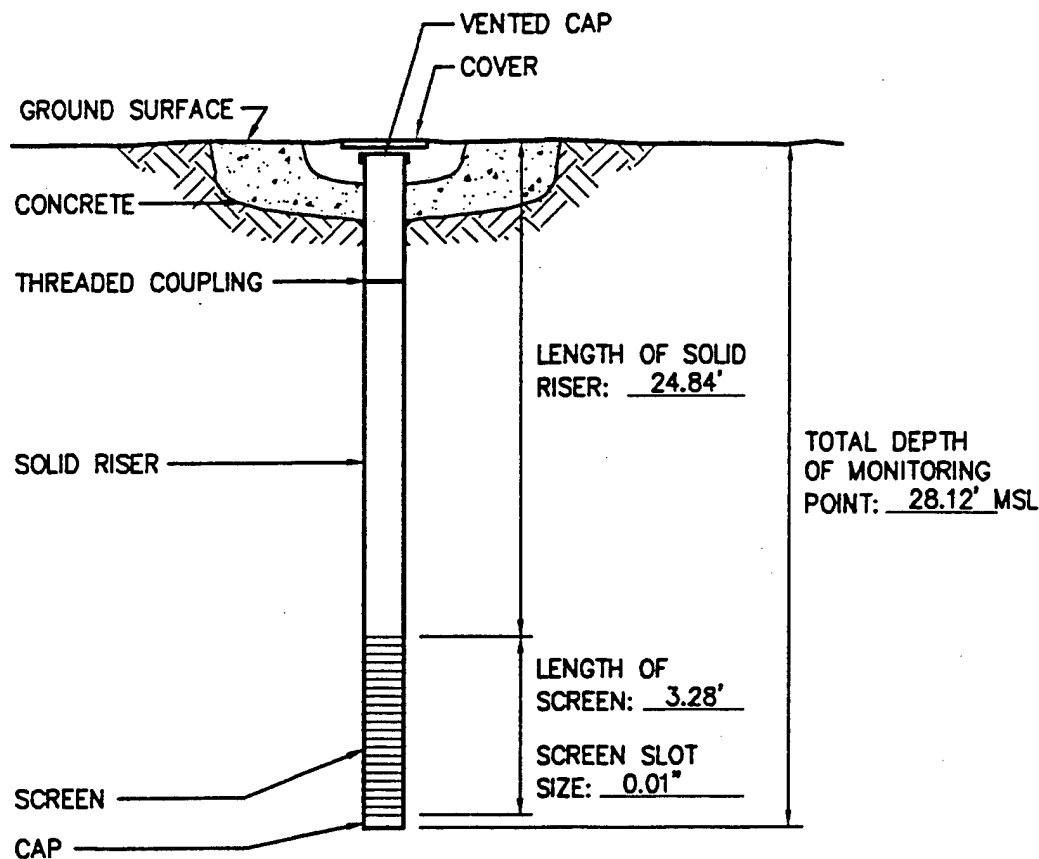
(NOT TO SCALE)

MEASUREMENT DATE: 8/23/94

STABILIZED WATER LEVEL __26.91__ FEET BELOW DATUM.

TOTAL MONITORING POINT DEPTH __28.12__ FEET BELOW DATUM.

GROUND SURFACE _____ FEET MSL

MONITORING POINT INSTALLATION RECORD

Site 3 (Fire Training Area)
Intrinsic Remediation RAP
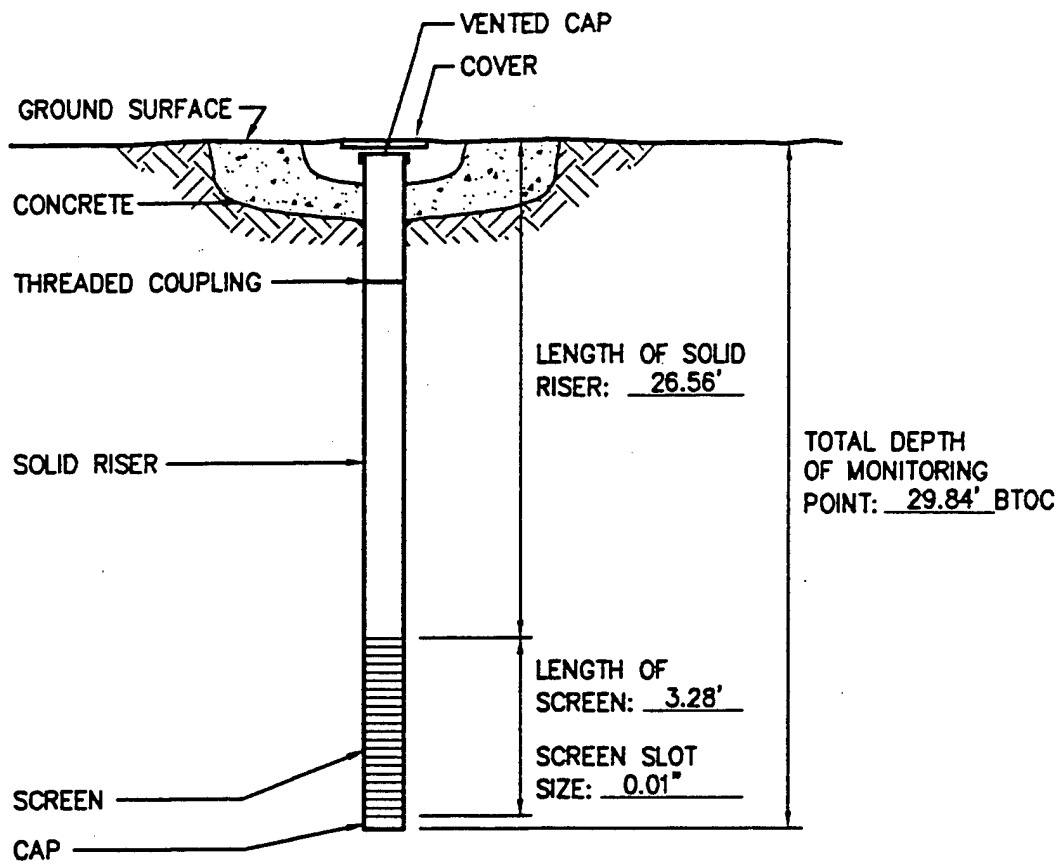Michigan Air National Guard, W.K. Kellogg Airport
Battle Creek, Michigan

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

M:\45010\DRAWINGS\ESMP-9S, 1/16/95 at 10:35

MONITORING POINT INSTALLATION RECORD

JOB NAME __BATTLE CREEK ANGB__ MONITORING POINT NUMBER __ESMP-10S__

JOB NUMBER __722450.10__ INSTALLATION DATE __8/20/94__ LOCATION __SITE 3 (FIRE TRAINING AREA)__

DATUM ELEVATION __917.66 FT. MSL__ GROUND SURFACE ELEVATION __917.96 FT. MSL__

DATUM FOR WATER LEVEL MEASUREMENT __TOP OF CASING__

SCREEN DIAMETER & MATERIAL __1/2" ID, 3/4" OD PVC__ SLOT SIZE __0.01"__

RISER DIAMETER & MATERIAL __1/2" ID, 3/4" OD PVC__ BOREHOLE DIAMETER __1.4" O.D.__

CONE PENETROMETER CONTRACTOR __US ARMY CORP OF ENGINEERS__ ES REPRESENTATIVE __T.H.__

VENTED CAP

COVER

GROUND SURFACE

CONCRETE

THREADED COUPLING

LENGTH OF SOLID RISER: __24.15'__

SOLID RISER

TOTAL DEPTH OF MONITORING POINT: __27.43'__ BTOC

LENGTH OF SCREEN: __3.28'__

SCREEN SLOT SIZE: __0.01"__

SCREEN

CAP
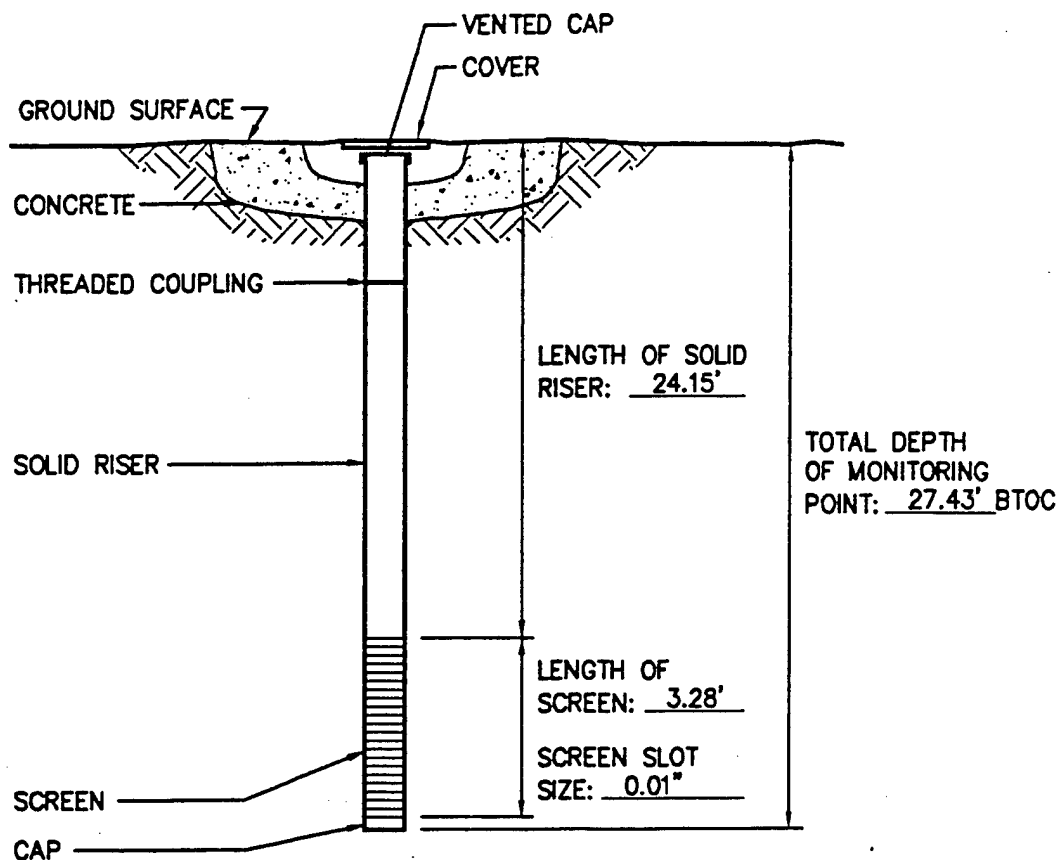
(NOT TO SCALE)

MEASUREMENT DATE: 8/23/94

STABILIZED WATER LEVEL __25.85__ FEET BELOW DATUM.

TOTAL MONITORING POINT DEPTH __27.43__ FEET BELOW DATUM.

GROUND SURFACE __917.96__ FEET MSL

MONITORING POINT INSTALLATION RECORD

Site 3 (Fire Training Area)
Intrinsic Remediation RAP
Michigan Air National Guard, W.K. Kellogg Airport
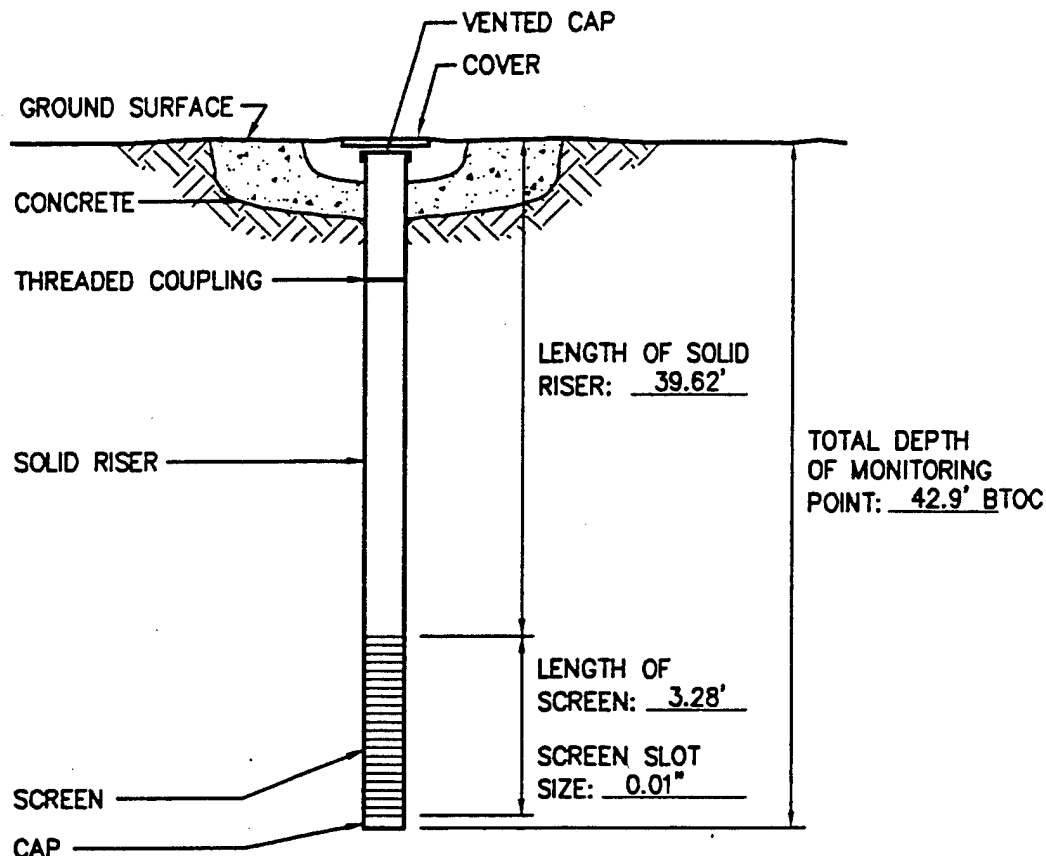Battle Creek, Michigan

PARSONS ENGINEERING SCIENCE, INC.

Denver, Colorado

MONITORING POINT INSTALLATION RECORD

JOB NAME __BATTLE CREEK ANGB__   MONITORING POINT NUMBER __ESMP-10D__

JOB NUMBER __722450.10__   INSTALLATION DATE __8/20/94__   LOCATION __SITE 3 (FIRE TRAINING AREA)__

DATUM ELEVATION __917.67 FT. MSL__   GROUND SURFACE ELEVATION _____

DATUM FOR WATER LEVEL MEASUREMENT __TOP OF CASING__

SCREEN DIAMETER & MATERIAL __1/2" ID, 3/4" OD PVC__   SLOT SIZE __0.01"__

RISER DIAMETER & MATERIAL __1/2" ID, 3/4" OD PVC__   BOREHOLE DIAMETER __1.4" O.D.__

CONE PENETROMETER CONTRACTOR __US ARMY CORP OF ENGINEERS__ ES REPRESENTATIVE __T.H.__

VENTED CAP

COVER

GROUND SURFACE

CONCRETE

THREADED COUPLING

LENGTH OF SOLID RISER: __38.71'__

SOLID RISER

TOTAL DEPTH OF MONITORING POINT: __41.99'__ BTOC

LENGTH OF SCREEN: __3.28'__

SCREEN SLOT SIZE: __0.01"__

SCREEN

CAP
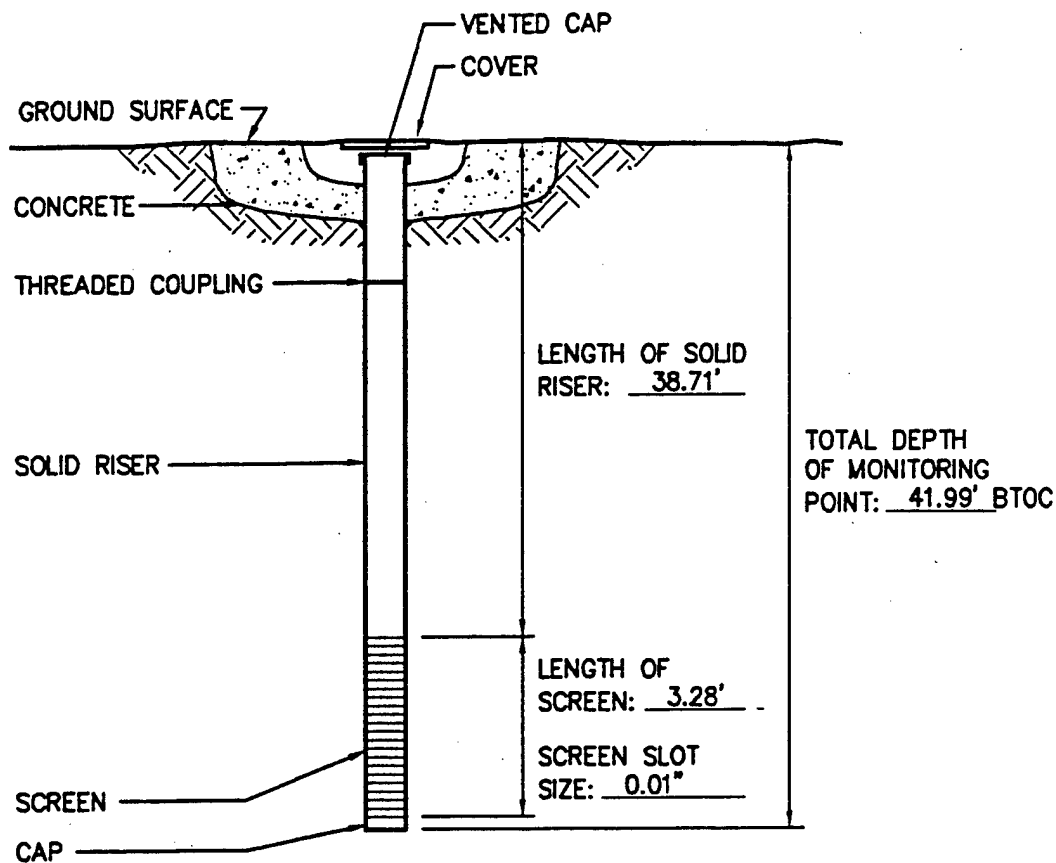
(NOT TO SCALE)

MEASUREMENT DATE: 8/23/94

STABILIZED WATER LEVEL __25.85__ FEET BELOW DATUM.

TOTAL MONITORING POINT DEPTH __41.99__ FEET BELOW DATUM.

GROUND SURFACE _____ FEET MSL

MONITORING POINT INSTALLATION RECORD

Site 3 (Fire Training Area)
Intrinsic Remediation RAP
Michigan Air National Guard, W.K. Kellogg Airport
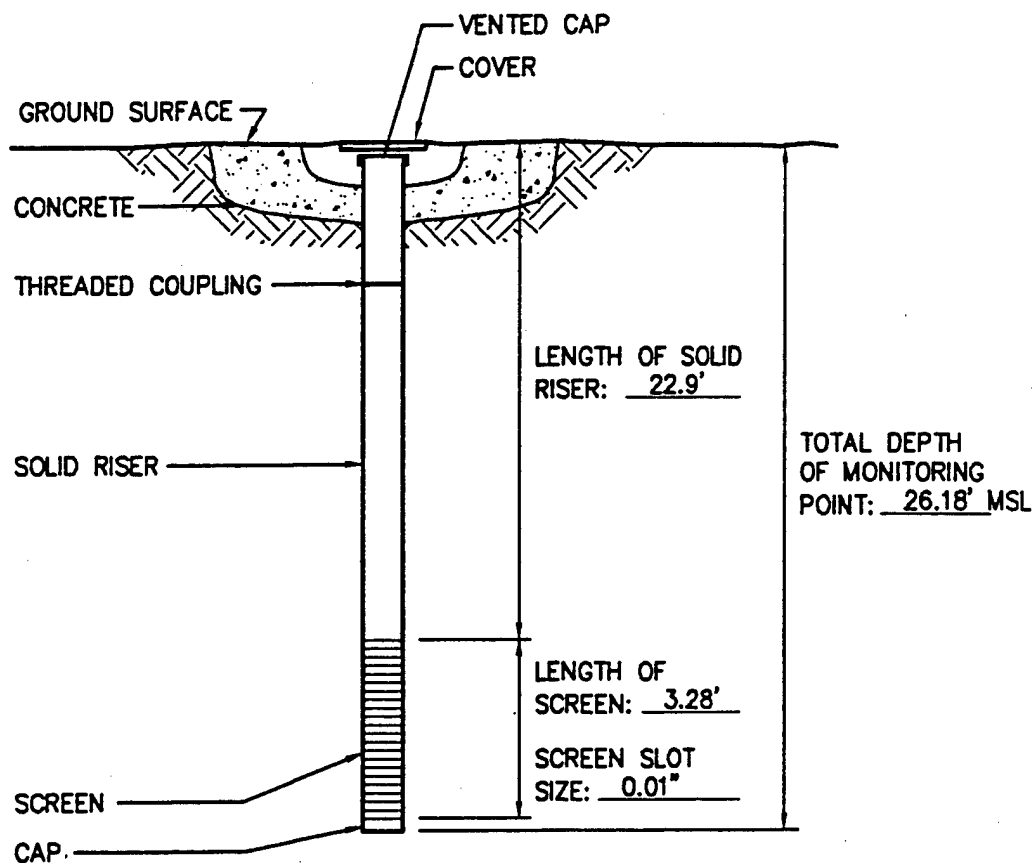Battle Creek, Michigan

PARSONS ENGINEERING SCIENCE, INC.

Denver, Colorado

MONITORING POINT INSTALLATION RECORD

JOB NAME __BATTLE CREEK ANGB__ MONITORING POINT NUMBER __ESMP-11S__

JOB NUMBER __722450.10__ INSTALLATION DATE __8/21/94__ LOCATION __SITE 3 (FIRE TRAINING AREA)__

DATUM ELEVATION __911.2 FT. MSL__ GROUND SURFACE ELEVATION __908.15 FT. MSL__

DATUM FOR WATER LEVEL MEASUREMENT __TOP OF CASING__

SCREEN DIAMETER & MATERIAL __1/2" ID, 3/4" OD PVC__ SLOT SIZE __0.01"__

RISER DIAMETER & MATERIAL __1/2" ID, 3/4" OD PVC__ BOREHOLE DIAMETER __1.4" O.D.__

CONE PENETROMETER CONTRACTOR __US ARMY CORP OF ENGINEERS__ ES REPRESENTATIVE __T.H.__

LOCKABLE STEEL PROTECTIVE CASING

GRAVEL PAD

GROUND SURFACE

THREADED COUPLING

LENGTH OF SOLID RISER: __24.51'__

SOLID RISER

TOTAL DEPTH OF MONITORING POINT: __27.79'__ BTOC

LENGTH OF SCREEN: __3.28'__

SCREEN SLOT SIZE: __0.01"__

SCREEN

CAP
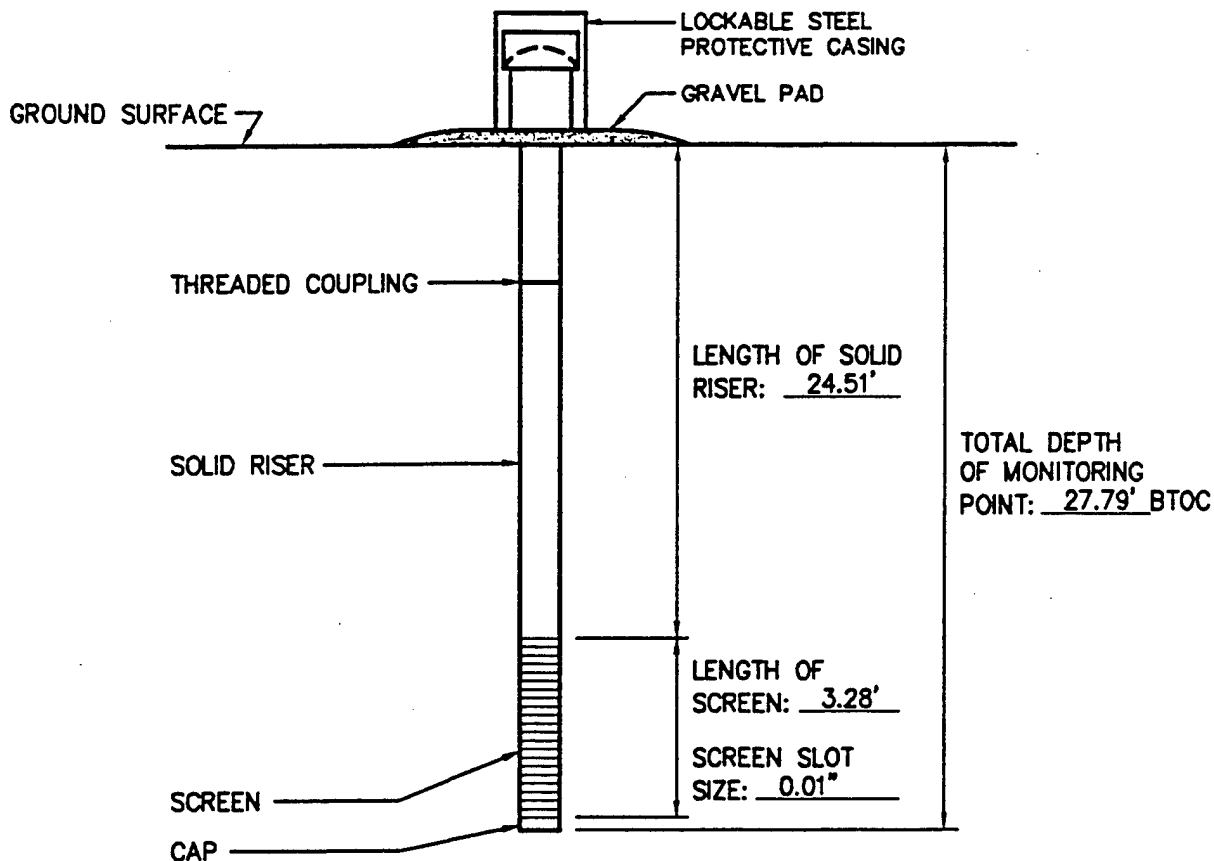
(NOT TO SCALE)

MEASUREMENT DATE: 8/23/94

STABILIZED WATER LEVEL __20.88__ FEET BELOW DATUM.

TOTAL MONITORING POINT DEPTH __27.79__ FEET FEET BELOW DATUM.

GROUND SURFACE __908.15__ FEET MSL

MONITORING POINT INSTALLATION RECORD

Site 3 (Fire Training Area)
Intrinsic Remediation RAP
Michigan Air National Guard, W.K. Kellogg Airport
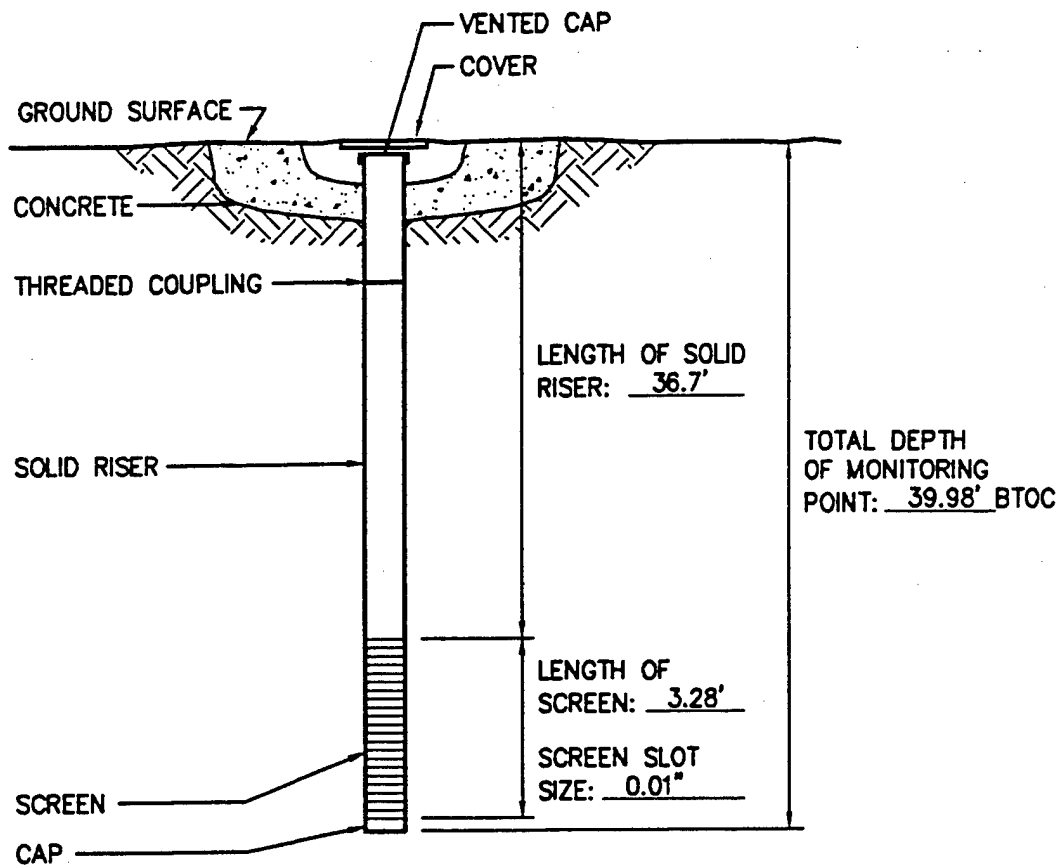Battle Creek, Michigan

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

MONITORING POINT INSTALLATION RECORD

JOB NAME __BATTLE CREEK ANGB__   MONITORING POINT NUMBER __ESMP–11D__
JOB NUMBER __722450.10__   INSTALLATION DATE __8/21/94__   LOCATION __SITE 3 (FIRE TRAINING AREA)__
DATUM ELEVATION __911.18 FT. MSL__   GROUND SURFACE ELEVATION _____
DATUM FOR WATER LEVEL MEASUREMENT __TOP OF CASING__
SCREEN DIAMETER & MATERIAL __1/2" ID, 3/4" OD PVC__   SLOT SIZE __0.01"__
RISER DIAMETER & MATERIAL __1/2" ID, 3/4" OD PVC__   BOREHOLE DIAMETER __1.4" O.D.__
CONE PENETROMETER CONTRACTOR __US ARMY CORP OF ENGINEERS__ ES REPRESENTATIVE __T.H.__

LOCKABLE STEEL PROTECTIVE CASING

GRAVEL PAD

GROUND SURFACE

THREADED COUPLING

LENGTH OF SOLID RISER: __40.6'__

SOLID RISER

TOTAL DEPTH OF MONITORING POINT: __43.88' MSL__

LENGTH OF SCREEN: __3.28'__

SCREEN SLOT SIZE: __0.01"__

SCREEN

CAP
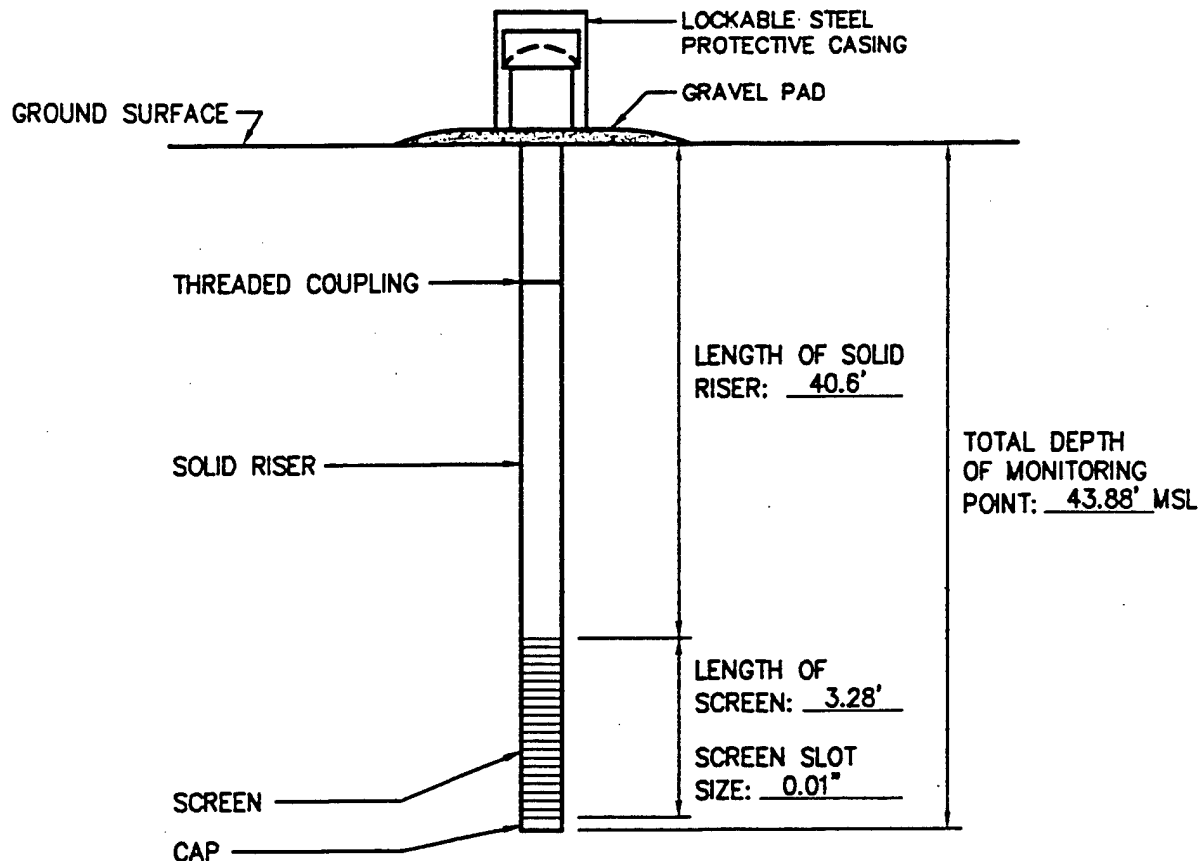
(NOT TO SCALE)

MEASURMENT DATE: 8/23/94
STABILIZED WATER LEVEL __20.85__ FEET BELOW DATUM.

TOTAL MONITORING POINT DEPTH __43.88__ FEET FEET BELOW DATUM.

GROUND SURFACE _____ FEET MSL

MONITORING POINT INSTALLATION RECORD

Site 3 (Fire Training Area)
Intrinsic Remediation RAP
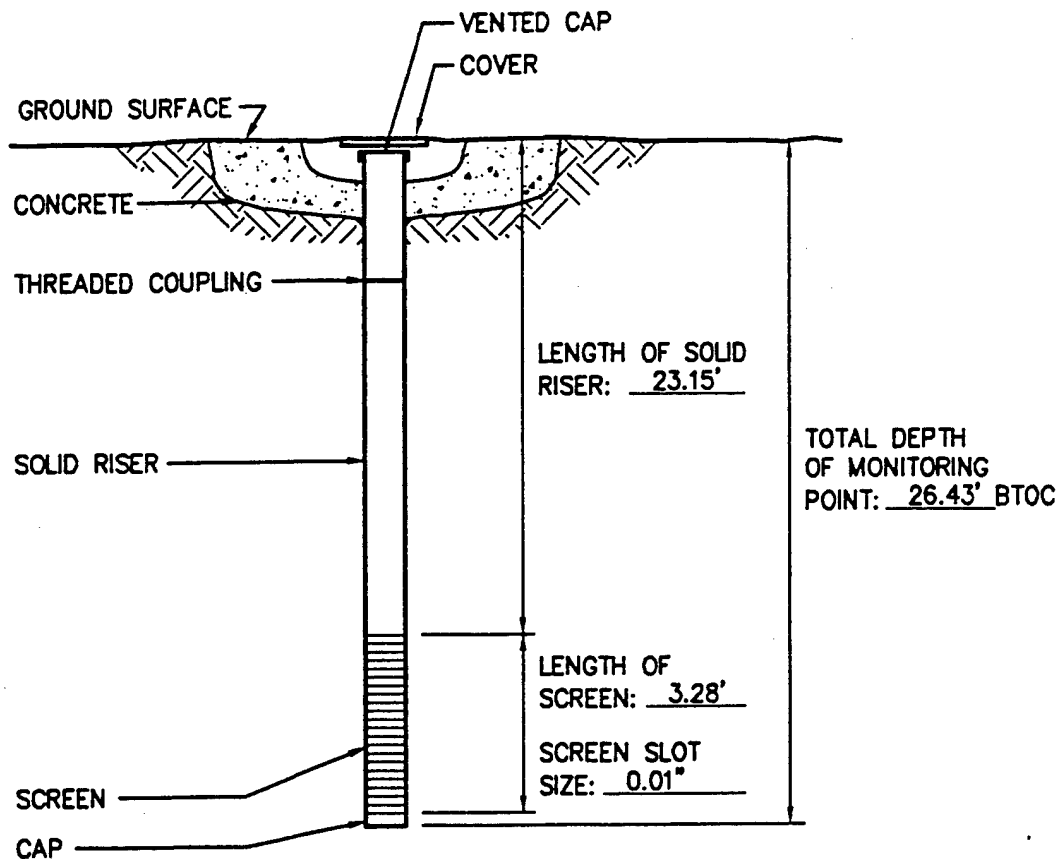Michigan Air National Guard, W.K. Kellogg Airport
Battle Creek, Michigan

PARSONS ENGINEERING SCIENCE, INC.

Denver, Colorado

MONITORING POINT INSTALLATION RECORD

JOB NAME __BATTLE CREEK ANGB__   MONITORING POINT NUMBER __ESMP-12S__

JOB NUMBER __722450.10__   INSTALLATION DATE __8/21/94__   LOCATION __SITE 3 (FIRE TRAINING AREA)__

DATUM ELEVATION __914.32 FT. MSL__   GROUND SURFACE ELEVATION __911.97 FT. MSL__

DATUM FOR WATER LEVEL MEASUREMENT __TOP OF CASING__

SCREEN DIAMETER & MATERIAL __1/2" ID, 3/4" OD PVC__   SLOT SIZE __0.01"__

RISER DIAMETER & MATERIAL __1/2" ID, 3/4" OD PVC__   BOREHOLE DIAMETER __1.4" O.D.__

CONE PENETROMETER CONTRACTOR __US ARMY CORP OF ENGINEERS__ ES REPRESENTATIVE __T.H.__

LOCKABLE STEEL PROTECTIVE CASING

GRAVEL PAD

GROUND SURFACE

THREADED COUPLING

LENGTH OF SOLID RISER: __29.21'__

SOLID RISER

TOTAL DEPTH OF MONITORING POINT: __32.49'__ BTOC

LENGTH OF SCREEN: __3.28'__

SCREEN SLOT SIZE: __0.01"__

SCREEN

CAP
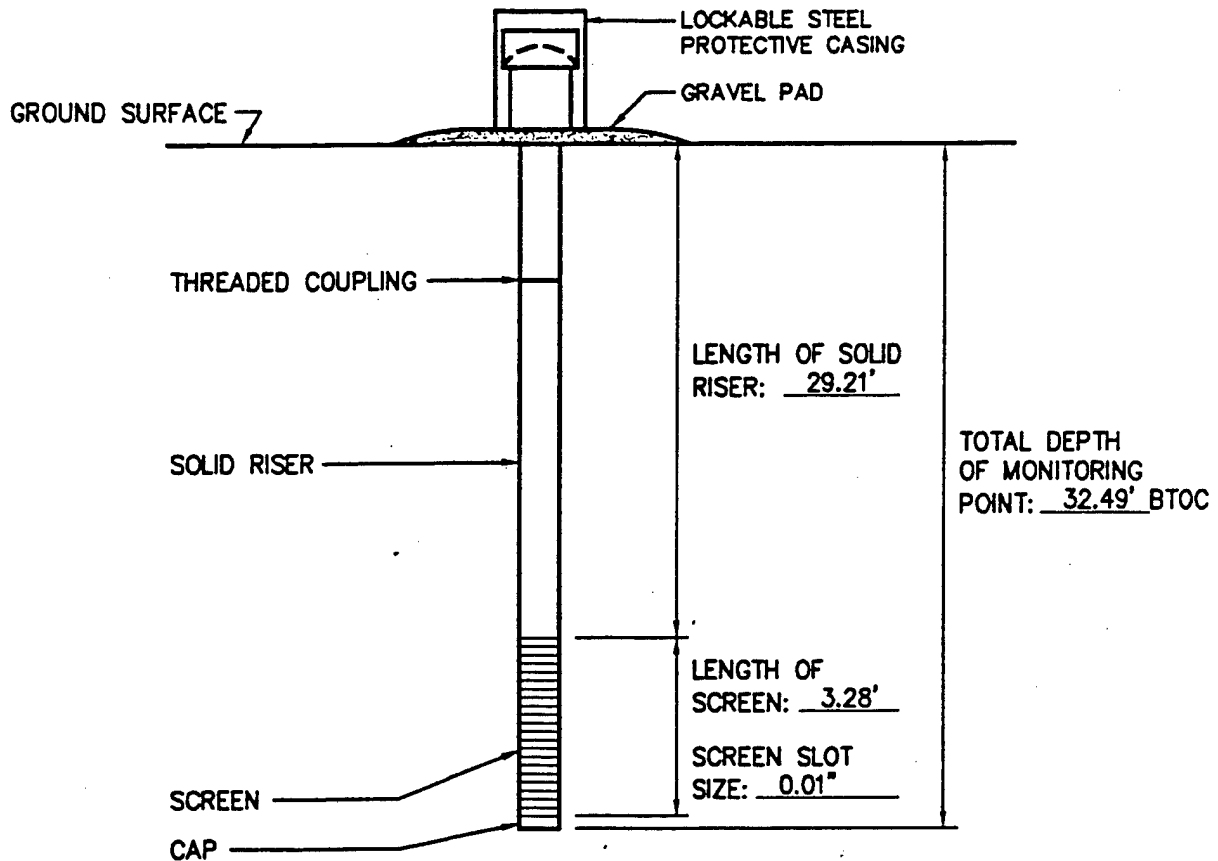
(NOT TO SCALE)

MEASUREMENT DATE: 8/23/94
STABILIZED WATER LEVEL __25.14__ FEET BELOW DATUM.

TOTAL MONITORING POINT DEPTH __32.49__ FEET FEET BELOW DATUM.

GROUND SURFACE __911.97__ FEET MSL

MONITORING POINT INSTALLATION RECORD

Site 3 (Fire Training Area)
Intrinsic Remediation RAP
Michigan Air National Guard, W.K. Kellogg Airport
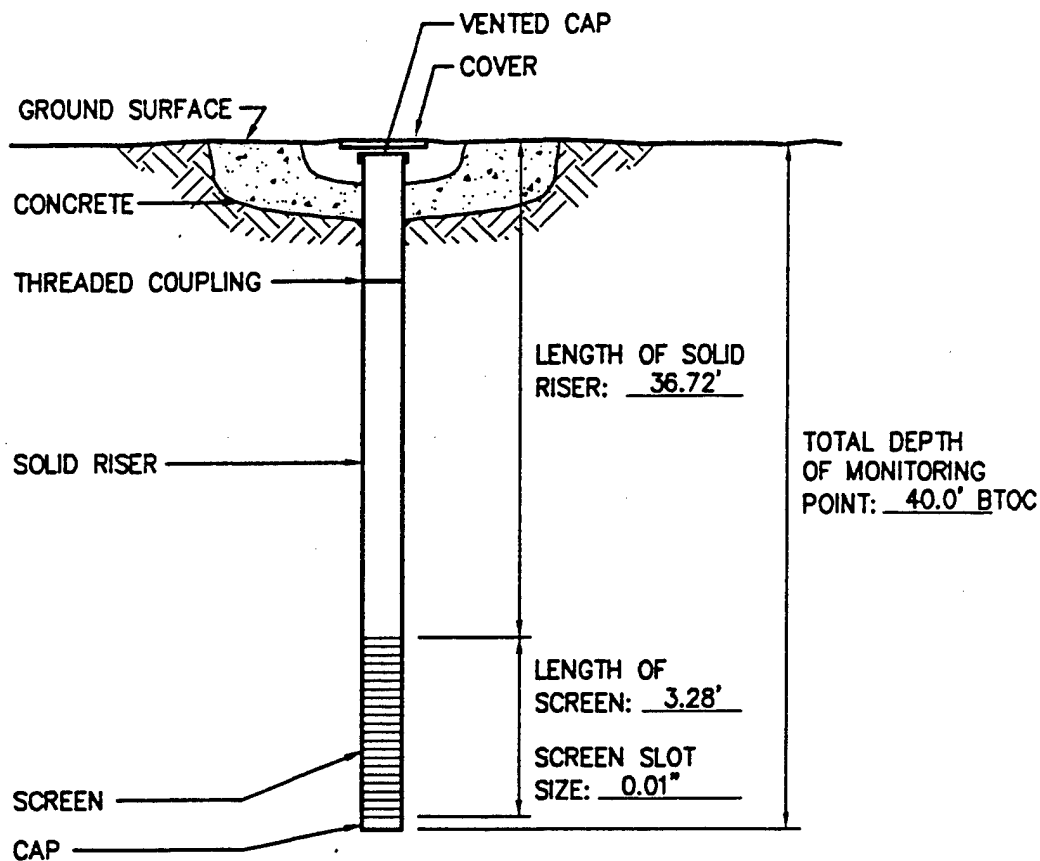Battle Creek, Michigan

PARSONS ENGINEERING SCIENCE, INC.

Denver, Colorado

M:\45010\DRAWINGS\ESMP-12S, 1/16/95 at 10:00

MONITORING POINT INSTALLATION RECORD

JOB NAME __BATTLE CREEK ANGB__   MONITORING POINT NUMBER __ESMP-12D__

JOB NUMBER __722450.10__ INSTALLATION DATE __8/21/94__ LOCATION __SITE 3 (FIRE TRAINING AREA)__

DATUM ELEVATION __914.47 FT. MSL__   GROUND SURFACE ELEVATION _____

DATUM FOR WATER LEVEL MEASUREMENT __TOP OF CASING__

SCREEN DIAMETER & MATERIAL __1/2" ID, 3/4" OD PVC__   SLOT SIZE __0.01"__

RISER DIAMETER & MATERIAL __1/2" ID, 3/4" OD PVC__ BOREHOLE DIAMETER __1.4" O.D.__

CONE PENETROMETER CONTRACTOR __US ARMY CORP OF ENGINEERS__ ES REPRESENTATIVE __T.H.__

LOCKABLE STEEL PROTECTIVE CASING

GRAVEL PAD

GROUND SURFACE

THREADED COUPLING

SOLID RISER

LENGTH OF SOLID RISER: __48.06'__

TOTAL DEPTH OF MONITORING POINT: __51.34'__ BTOC

LENGTH OF SCREEN: __3.28'__

SCREEN SLOT SIZE: __0.01"__

SCREEN

CAP
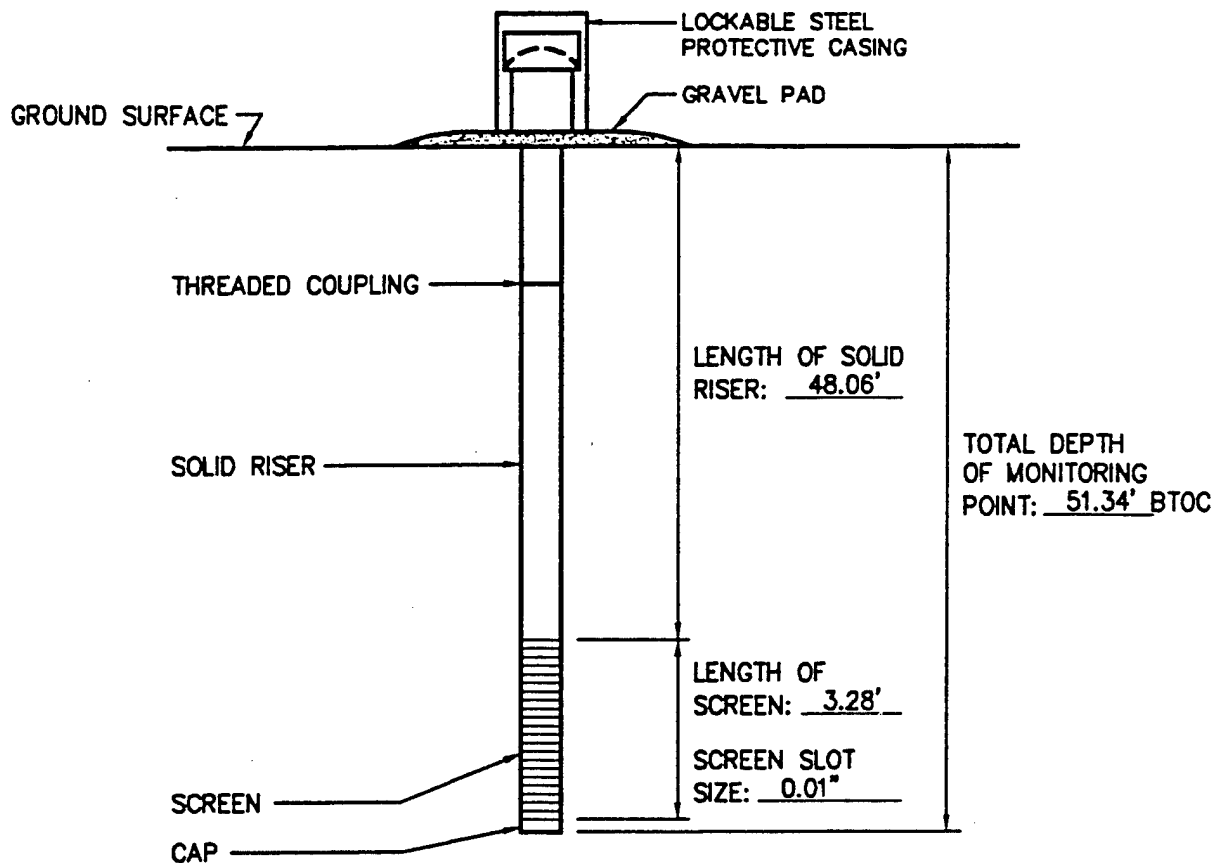
(NOT TO SCALE)

MEASUREMENT DATE: 8/23/94

STABILIZED WATER LEVEL __25.06__ FEET BELOW DATUM.

TOTAL MONITORING POINT DEPTH __51.34__ FEET BELOW DATUM.

GROUND SURFACE _____ FEET MSL

MONITORING POINT INSTALLATION RECORD

Site 3 (Fire Training Area)
Intrinsic Remediation RAP
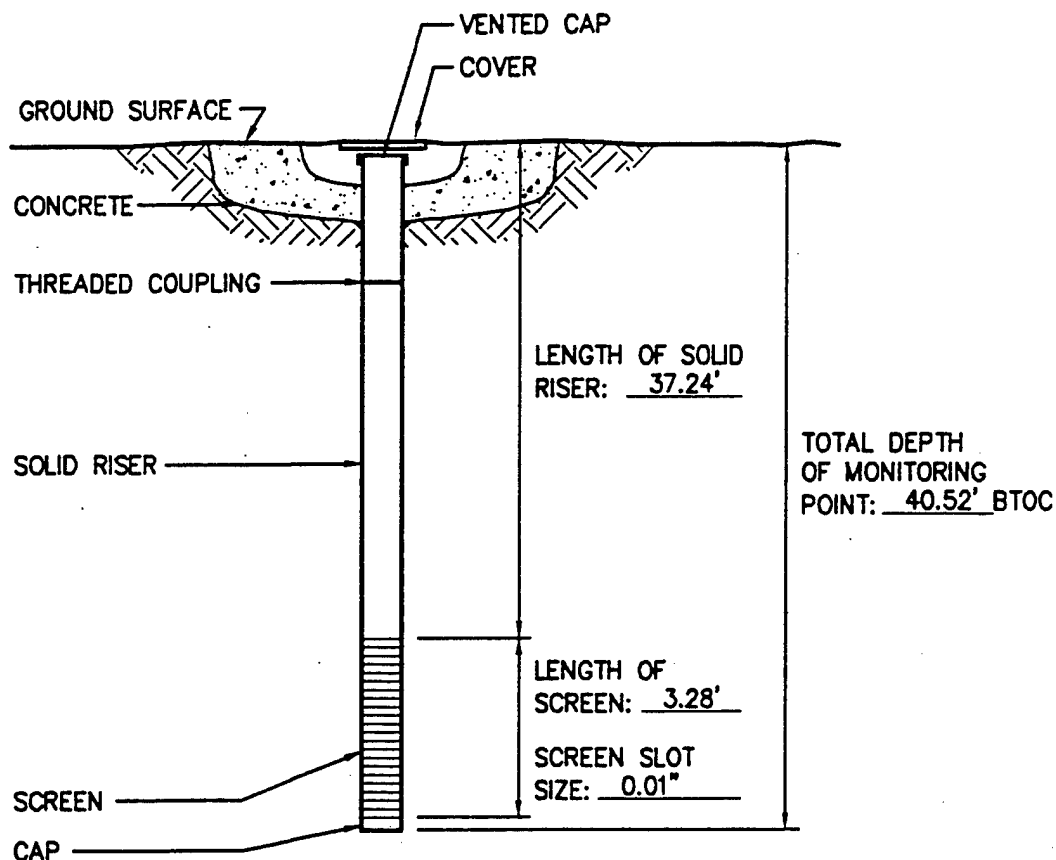Michigan Air National Guard, W.K. Kellogg Airport
Battle Creek, Michigan

PARSONS ENGINEERING SCIENCE, INC.

Denver, Colorado

M:\45010\DRAWINGS\ESMP-12D, 1/16/95 at 10:00

MONITORING POINT INSTALLATION RECORD

JOB NAME __BATTLE CREEK ANGB__ MONITORING POINT NUMBER __ESMP-1D__

JOB NUMBER __722450.10__ INSTALLATION DATE __8/19/94__ LOCATION __SITE 3 (FIRE TRAINING AREA)__

DATUM ELEVATION __919.09 FT MSL__ GROUND SURFACE ELEVATION _____

DATUM FOR WATER LEVEL MEASUREMENT __TOP OF CASING__

SCREEN DIAMETER & MATERIAL __1/2" ID, 3/4" OD PVC__ SLOT SIZE __0.01"__

RISER DIAMETER & MATERIAL __1/2" ID, 3/4" OD PVC__ BOREHOLE DIAMETER __1.4"__

CONE PENETROMETER CONTRACTOR __US ARMY CORP OF ENGINEERS__ ES REPRESENTATIVE __T.H.__

VENTED CAP

COVER

GROUND SURFACE

CONCRETE

THREADED COUPLING

LENGTH OF SOLID RISER: __40.89'__

SOLID RISER

TOTAL DEPTH OF MONITORING POINT: __44.17'__ BTOC

LENGTH OF SCREEN: __3.28'__

SCREEN SLOT SIZE: __0.01"__

SCREEN

CAP
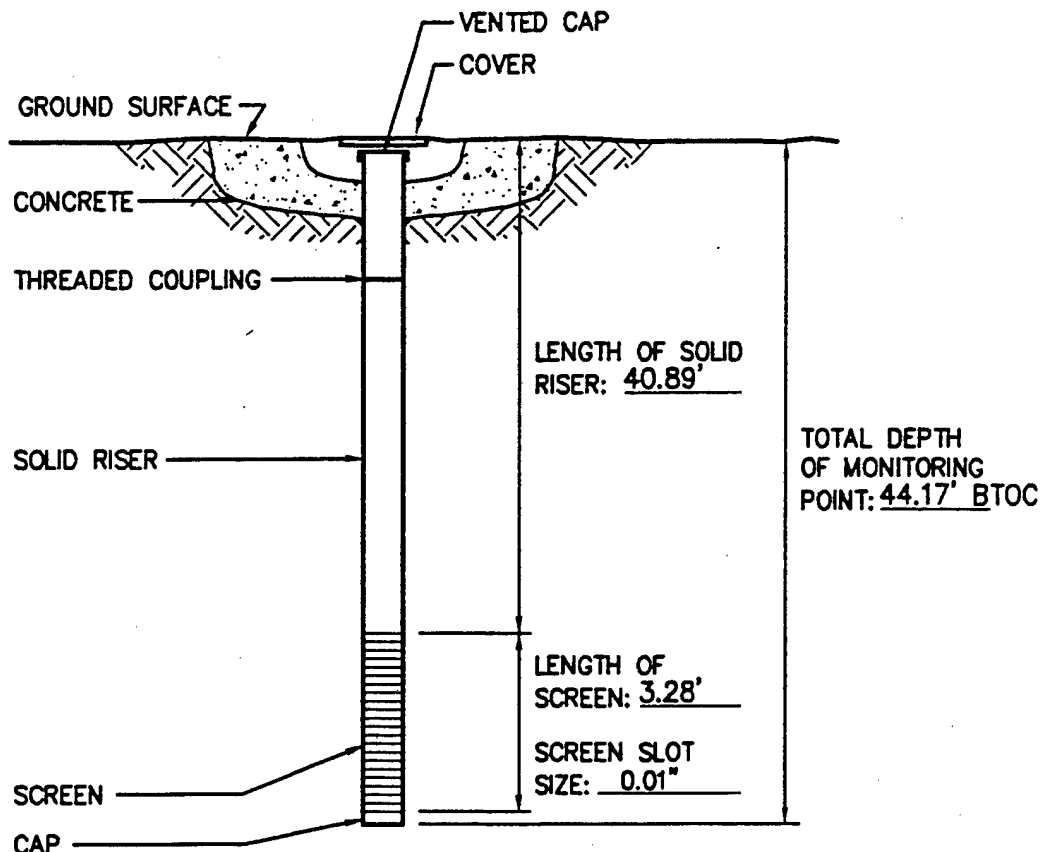
(NOT TO SCALE)

MEASUREMENT 8/23/94

STABILIZED WATER LEVEL __26.93__ FEET BELOW DATUM.

TOTAL MONITORING POINT DEPTH __44.17__ FEET BELOW DATUM.

GROUND SURFACE _____ FEET MSL

MONITORING POINT INSTALLATION RECORD

Site 3 (Fire Training Area)
Intrinsic Remediation RAP
Michigan Air National Guard, W.K. Kellogg Airport
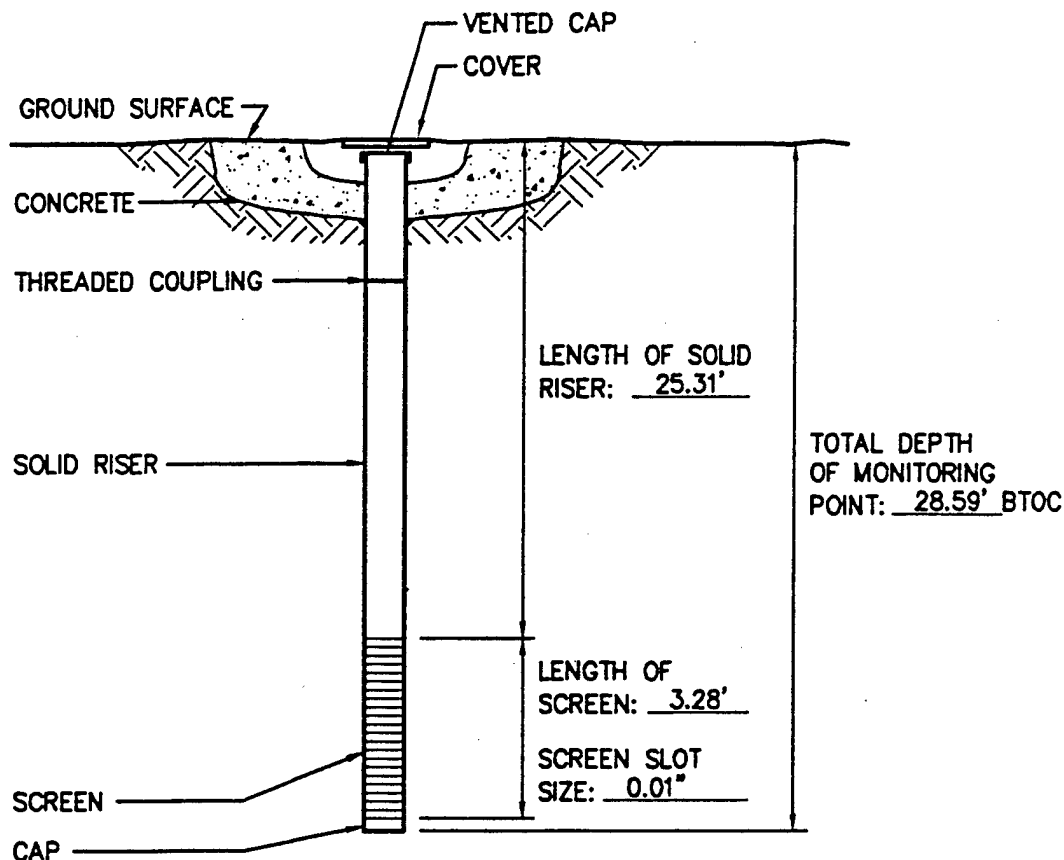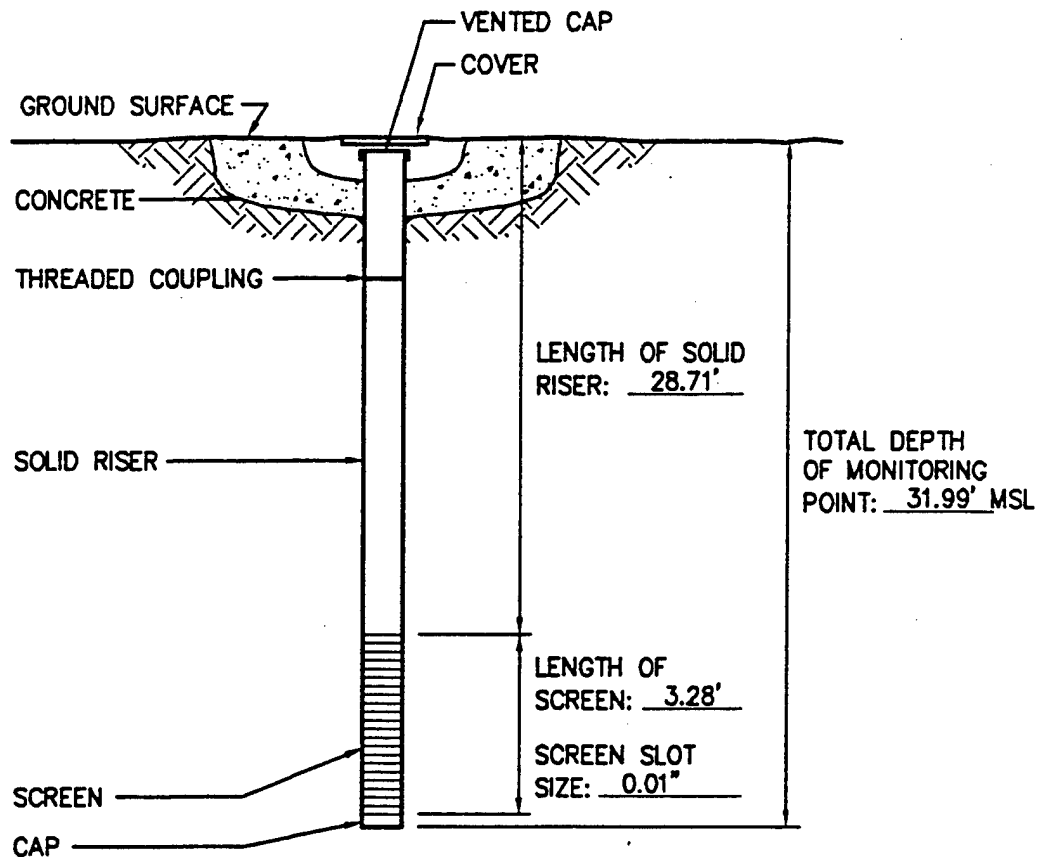Battle Creek, Michigan

**PARSONS
ENGINEERING SCIENCE, INC.**

Denver, Colorado

M:\45010\DRAWINGS\ESMP-1D, 1/16/95 at 1:10

PARSONS ENGINEERING SCIENCE	Client: AFCEE
Project No.: 722450.10	Location: SITE3, BATTLE CREEK, MI

BC3—MW1 FALLING HEAD TEST #1

DATA SET:
c:\aqt\bcdata\mw1_1.dat
11/11/94

AQUIFER TYPE:
Unconfined
SOLUTION METHOD:
Bouwer-Rice
TEST DATE:
8/23/94
TEST WELL:
BC3-MW1

ESTIMATED PARAMETERS:
K = 0.008759 ft/min
y0 = 0.507 ft

TEST DATA:
H0 = 1.004 ft
rc = 0.0833 ft
rw = 0.28 ft
L = 15. ft
b = 18. ft
H = 12.54 ft

Displacement (ft) vs Time (min)

PARSONS ENGINEERING SCIENCE	Client: AFCEE
Project No.: 722450.10	Location: SITE3, BATTLE CREEK, MI

BC3-MW1 FALLING HEAD TEST #2

DATA SET:
mw1_2.dat
11/10/94

AQUIFER TYPE:
Unconfined
SOLUTION METHOD:
Bouwer-Rice
TEST DATE:
8/23/94
TEST WELL:
BC3-MW1

ESTIMATED PARAMETERS:
K = 0.01314 ft/min
y0 = 0.5026 ft

TEST DATA:
H0 = 0.89 ft
rc = 0.0833 ft
rw = 0.28 ft
L = 15. ft
b = 18. ft
H = 12.54 ft

Plot: Displacement (ft) vs Time (min), vertical axis from 0.1 to 1., horizontal axis from 0. to 2.

PARSONS ENGINEERING SCIENCE | Client: AFCEE

Location: SITE3, BATTLE CREEK, MI

Project No.: 722450.10

BC3-MW1 RISING HEAD TEST #2

DATA SET:
mw1_4.dat
11/10/94

AQUIFER TYPE:
Unconfined
SOLUTION METHOD:
Bouwer-Rice
TEST DATE:
8/23/94
TEST WELL:
BC3-MW1

ESTIMATED PARAMETERS:
K = 0.01011 ft/min
y0 = 0.01731 ft

TEST DATA:
H0 = 0.739 ft
rc = 0.0833 ft
rw = 0.28 ft
L = 15. ft
b = 18. ft
H = 12.54 ft

PARSONS ENGINEERING SCIENCE

Client: AFCEE

Location: SITE3, BATTLE CREEK, MI

Project No.: 722450.10

BC3-MW2 RISING HEAD TEST #1

DATA SET:
mw2_2.dat
11/10/94

AQUIFER TYPE:
Unconfined
SOLUTION METHOD:
Bouwer-Rice
TEST DATE:
8/23/94
TEST WELL:
BC3-MW2

ESTIMATED PARAMETERS:
K = 0.01363 ft/min
y0 = 0.1259 ft

TEST DATA:
H0 = 1.594 ft
rc = 0.0833 ft
rw = 0.28 ft
L = 15. ft
b = 18. ft
H = 12.42 ft

BC3-MW3 FALLING HEAD TEST #1

DATA SET:
MW3_1.DAT
11/11/94

AQUIFER TYPE:
Unconfined
SOLUTION METHOD:
Bouwer-Rice
TEST DATE:
8/23/94
TEST WELL:
BC3-MW3

ESTIMATED PARAMETERS:
$K = 0.001192$ ft/min
$y0 = 0.0378$ ft

TEST DATA:
$H0 = 0.75$ ft
$rc = 0.0833$ ft
$rw = 0.28$ ft
$L = 15.$ ft
$b = 17.$ ft
$H = 11.42$ ft

Displacement (ft) vs. Time (min)

PARSONS ENGINEERING SCIENCE

Client: AFCEE

Project No.: 722450.10

Location: SITE3, BATTLE CREEK, MI

BC3-MW3 RISING HEAD TEST #2

DATA SET:
MW3_4.DAT
11/11/94

AQUIFER TYPE:
Unconfined
SOLUTION METHOD:
Bouwer-Rice
TEST DATE:
8/23/94
TEST WELL:
BC3-MW3

ESTIMATED PARAMETERS:
K = 0.02015 ft/min
y0 = 0.08111 ft

TEST DATA:
H0 = 5.409 ft
rc = 0.0833 ft
rw = 0.28 ft
L = 15. ft
b = 17. ft
H = 11.42 ft

PARSONS ENGINEERING SCIENCE

Client: AFCEE

Project No.: 722450.10

Location: SITE 3, BATTLE CREEK, MI

BC3—MW5 FALLING HEAD TEST #1

DATA SET:
MW5_1.DAT
11/11/94

AQUIFER TYPE:
Unconfined
SOLUTION METHOD:
Bouwer-Rice
TEST DATE:
8/23/94
TEST WELL:
BC3-MW5

ESTIMATED PARAMETERS:
K = 0.004228 ft/min
y0 = 0.2018 ft

TEST DATA:
H0 = 1.153 ft
rc = 0.0833 ft
rw = 0.28 ft
L = 15. ft
b = 18. ft
H = 13.12 ft .

Parsons Engineering Science

Project No.: 722450.10

Client: AFCEE

Location: **Site 3, Battle Creek, MI**

MW5 Rising Head Test #1

DATA SET:
MW5_2.DAT
11/11/94

AQUIFER TYPE:
Unconfined
SOLUTION METHOD:
Bouwer-Rice
TEST DATE:
8/23/94
TEST WELL:
BC3-MW5

ESTIMATED PARAMETERS:
K = 0.01263 ft/min
y0 = 0.5991 ft

TEST DATA:
H0 = 4.674 ft
rc = 0.0833 ft
rw = 0.28 ft
L = 15. ft
b = 18. ft
H = 13.12 ft

Displacement (ft)

Time (min)

PARSONS ENGINEERING SCIENCE

Client: AFCEE

Location: SITE3, BATTLE CREEK, MI

Project No.: 722450.10

BC3-MW5 FALLING HEAD TEST #2

DATA SET:
MW5_3.DAT
11/11/94

AQUIFER TYPE:
Unconfined
SOLUTION METHOD:
Bouwer-Rice
TEST DATE:
8/23/94
TEST WELL:
BC3-MW5

ESTIMATED PARAMETERS:
K = 0.003797 ft/min
y0 = 0.2358 ft

TEST DATA:
H0 = 0.871 ft
rc = 0.0833 ft
rw = 0.28 ft
L = 15. ft
b = 18. ft
H = 13.12 ft

PARSONS ENGINEERING SCIENCE

Client: AFCEE

Location: SITE3, BATTLE CREEK, MI

Project No.: 722450.10

BC3-MW5 RISING HEAD TEST #2

DATA SET:
MW5_4.DAT
11/11/94

AQUIFER TYPE:
Unconfined
SOLUTION METHOD:
Bouwer-Rice
TEST DATE:
8/23/94
TEST WELL:
BC3-MW5

ESTIMATED PARAMETERS:
K = 0.00997 ft/min
y0 = 0.1847 ft

TEST DATA:
H0 = 4.989 ft
rc = 0.0833 ft
rw = 0.28 ft
L = 15. ft
b = 18. ft
H = 13.12 ft

PARSONS ENGINEERING SCIENCE

Client: AFCEE

Project No.: 722450.10

Location: SITE3, BATTLE CREEK, MI

BC3-MW6 FALLING HEAD TEST #1

DATA SET:
mw6_1.dat
11/10/94

AQUIFER TYPE:
Unconfined
SOLUTION METHOD:
Bouwer-Rice
TEST DATE:
8/23/94
TEST WELL:
BC3-MW6

ESTIMATED PARAMETERS:
K = 0.004707 ft/min
y0 = 0.1445 ft

TEST DATA:
H0 = 2.853 ft
rc = 0.0833 ft
rw = 0.28 ft
L = 15. ft
b = 17. ft
H = 11.99 ft

Displacement (ft) vs Time (min)

PARSONS ENGINEERING SCIENCE

Client: AFCEE

Project No.: 722450.10

Location: SITE3, BATTLE CREEK, MI

BC3-MW6 FALLING HEAD TEST #2

DATA SET:
mw6_2.dat
11/10/94

AQUIFER TYPE:
Unconfined
SOLUTION METHOD:
Bouwer-Rice
TEST DATE:
8/23/94
TEST WELL:
BC3-MW6

ESTIMATED PARAMETERS:
K = 0.004 ft/min
y0 = 0.4337 ft

TEST DATA:
H0 = 2.71 ft
rc = 0.0833 ft
rw = 0.28 ft
L = 15. ft
b = 17. ft
H = 11.99 ft

PARSONS ENGINEERING SCIENCE	Client: AFCEE
Project No.: 722450.10	Location: SITE3, BATTLE CREEK, MI

BC3-MW6 RISING HEAD TEST #1

DATA SET:
mw6_3.dat
11/10/94

AQUIFER TYPE:
Unconfined
SOLUTION METHOD:
Bouwer-Rice
TEST DATE:
8/23/94
TEST WELL:
BC3-MW6

ESTIMATED PARAMETERS:
K = 0.006474 ft/min
y0 = 0.4062 ft

TEST DATA:
H0 = 2.324 ft
rc = 0.0833 ft
rw = 0.28 ft
L = 15. ft
b = 17. ft
H = 11.99 ft

PARSONS ENGINEERING SCIENCE

Client: AFCEE

Project No.: 722450.10

Location: SITE3, BATTLE CREEK, MI

BC3-MW6 RISING HEAD TEST #2

DATA SET:
MW6_4.DAT
11/11/94

AQUIFER TYPE:
Unconfined
SOLUTION METHOD:
Bouwer-Rice
TEST DATE:
8/23/94
TEST WELL:
BC3-MW6

ESTIMATED PARAMETERS:
K = 0.007637 ft/min
y0 = 0.6660 ft

TEST DATA:
H0 = 2.035 ft
rc = 0.0833 ft
rw = 0.28 ft
L = 15. ft
b = 17. ft
H = 11.99 ft

APPENDIX B

SOIL AND GROUNDWATER ANALYTICAL DATA

Volatile Fatty acids Analysis by GC/MS

Battle Creek NGS - Samples 89ESMP2S and 89ESMP10S

Concentrations of phenols and aliphatic/aromatic acids found in these two water samples were very low. With the lowest detectable level at 5 ppb, sample 89ESMP2S contained only 2-ethylhexanoic acid while the same component plus hexanoic acid and m,o,p-tolylacetic acids were present in 89ESMP10S.

) The results indicate that microbial biodegradation has diminished because of low substrate hydrocarbon constituents.

Battle Creek National Guard Station

Sample	Total Petroleum Hydrocarbons mg TPH/Kilogram soil	Moisture % Dry weight
ESSB - 1	60	17.7
ESSB - 2	< 60	20.9
ESSB - 3	9910	6.6
ESSB - 4	6490	24.4
ESSB - 5	< 60	6.5
ESSB - 6	< 60	2.7
ESSB - 7	< 60	7.9
ESSB - 8	< 60	5.2
ESSB - 9	4700	9.0
ESSB - 10	600	5.0
ESSB - 11	2900	7.3
ESSB - 12	22810	2.4
ESSB - 13	< 60	5.7
ESSB - 14	48500	8.7
ESSB - 15	5310	9.0
ESSB - 16	390	13.2
ESSB - 17	< 60	13.6
ESSB - 18	2460	14.1
ESSB - 19	< 60	8.4
ESSB - 20	< 60	5.9
ESSB - 21	< 60	8.4
ESSB - 22	< 60	9.5
ESSB - 23	< 60	9.1
ESSB - 24	1020	7.4

MAN*AGEMENT*
TECH*NOLOGY*

Ref: 94-JH6/vg

August 31, 1994

Dr. Don Kampbell
R.S. Kerr Environmental Research Lab
U.S. Environmental Protection Agency
P.O. Box 1198
Ada, OK 74820

THRU: S.A. Vandegrift *SAV*

Dear Don:

Attached are TOC results for a set of 33 wellwaters submitted to ManTech Environmental August 16, 1994 under Service Request #SF-0-77. TOC determinations were begun August 29, 1994 and completed August 30, 1994 using RSKSOP-102.

A known AQC sample was analyzed with your samples for quality control.

If you have any questions concerning this data, please feel free to contact me.

Sincerely,

Jeff Hickerson

Jeff Hickerson

xc: R.L. Cosby
    J.L. Seeley *jb*

SAMPLES	MG/L OC
84ESMP 1S	53.9
84ESMP 1S dup	49.8
84ESMP 1D	0.7
89ESMP 2S	2.0
89ESMP 2D	0.7
89ESMP 3S	0.9
89ESMP 3D	0.7
89ESMP 3DD	0.7
89ESMP 4S	0.6
89ESMP 4D	0.6
89ESMP 5S	5.2
89ESMP 5S dup	4.2
89ESMP 5D	0.7
89ESMP 6S	0.5
89ESMP 6D	0.5
89ESMP 7S	15.6
89ESMP 7S dup	15.1
89ESMP 7D	3.1
89ESMP 8S	0.5
89ESMP 8D	2.8
89ESMP 9S	1.1
89ESMP 10S	6.9
89ESMP 10D	12.4
89ESMP 10D dup	0.6
89ESMP 10D trip.	0.6
89ESMP 11S	1.4
89ESMP 11D	4.2
89ESMP 12S	1.2
89ESMP 12D	2.1
89ESMP 13S	1.0
89BC3 MW 1	3.0
89BC3 MW 2	5.0
89BC3 MW 3	0.3
89BC3 MW 4	0.9
89BC3 MW 5	19.0
89BC3 MW5 dup	18.1
89BC3 MW 6	1.9
89BC5 MW 1	1.0
VENT WELL @ 3 FT	253.0
VENT WELL @ 3 FT	253.0
WPO32-I	42.39
	42.51
	42.20

TRUE VALUE: WPO32-I = 44.0 MG/L

MAN *AGEMENT*
TECH *NOLOGY*

Ref: 94-JAD39

October 11, 1994

Dr. Don Kampbell
R.S. Kerr Environmental Research Lab
U.S. Environmental Protection Agency
P.O. Box 1198
Ada, OK 74820

THRU: S.A. Vandegrift

Dear Don:

As requested in Service Request # SF-0-77, headspace GC/MS analysis of 33 Battle Creek water samples for volatile organic compounds + TMBs was completed. The samples were received on August 23, 1994 and analyzed on September 1-3, 1994. RSKSOP-148 (Determination of Volatile Organic Compounds in Water by Automated Headspace Gas Chromatography/Mass Spectrometry (Saturn II Ion Trap Detector) was used for this analysis.

An internal standard calibration method was established for 12 chlorinated and 9 aromatic compounds. The standard curves were prepared from 1.0 to 2000 ppb. The lower calibration limits were 1.0 ppb.

The sample was prepared by adding 10 ml of sample to a headspace vial containing 2 g of sodium chloride (NaCl). 8 µl of 125 µg/ml fluorobenzene was added to this 10 ml liquid volume before the vial was capped. The internal standard was at a concentration of 100 ppb in the headspace vial.

ManTech Environmental Research Services Corporation

R.S. Kerr Environmental Research Laboratory, P.O. Box 1198, 919 Kerr Research Drive
Ada, Oklahoma 74821-1198   405-436-8660   FAX 405-436-8501

A quantitation report for the sample, lab blank, and QC standards is presented in Table 1-3.

If you should have any questions, please feel free to contact me.

Sincerely,

John Allen Daniel

xc: R.L. Cosby
    G.B. Smith
    D.D. Fine
    J.L. Seeley

Table 1. Quantitation Report for Site # SF-0-77 from Battle Creek, MI.

Concentration = ppb

Compound	84ESMP1S	84ESMP1D	89ESMP2S	89ESMP2S Field Dup	89ESMP2D	89ESMP3S	89ESMP3D	89ESMP3DD	89ESMP4S	89ESMP4D
VINYL CHLORIDE	---	---	---	---	---	---	---	---	---	---
1,1-DICHLOROETHENE	---	---	---	---	---	---	---	---	---	---
T-1,2-DICHLOROETHENE	---	---	---	---	---	---	---	---	---	---
C-1,2-DICHLOROETHENE	22.7	---	1.0	1.0	---	---	---	---	---	---
CHLOROFORM	---	---	---	---	---	---	---	---	---	---
1,1,1-TRICHLOROETHANE	---	---	---	---	---	---	---	---	---	---
CARBON TETRACHLORIDE	25.9	---	---	---	---	---	---	---	---	---
BENZENE	---	---	---	---	---	---	---	---	---	---
1,2-DICHLOROETHANE	---	---	---	---	---	---	---	---	---	---
TRICHLOROETHENE	---	---	---	---	---	---	---	---	---	---
TOLUENE	4.3	2.2	---	1.0	---	---	---	---	---	2.3
TETRACHLOROETHENE	1.5	---	---	---	---	2.5	---	---	---	---
CHLOROBENZENE	---	---	---	---	---	---	---	---	---	---
ETHYLBENZENE	123	---	2.6	2.8	2.9	---	1.7	---	---	---
m+p-XYLENE	863	2.2	4.8	4.9	20.1	3.9	12.9	---	4.2	---
o-XYLENE	100	---	---	---	3.1	---	2.2	---	1.1	1.1
BROMOFORM	---	---	---	---	---	---	---	---	---	---
1,3,5-TRIMETHYLBENZENE	112	---	---	---	3.1	---	2.3	---	1.0	---
1,2,4-TRIMETHYLBENZENE	223	1.6 *	3.7 *	3.6 *	7.1 *	2.0 *	5.4 *	1.5 *	2.5 *	1.3 *
1,2,3-TRIMETHYLBENZENE	162	1.1 *	4.7 *	4.8 *	4.8 *	1.4 *	3.9 *	1.2 *	1.7 *	1.0 *

Compound	89ESMP5S	89ESMP5D Lab Dup	89ESMP6S	89ESMP6D	89ESMP7S	89ESMP7S Field Dup	89ESMP7D	89ESMP8S	89ESMP8D
VINYL CHLORIDE	---	---	---	---	---	---	---	---	---
1,1-DICHLOROETHENE	---	---	---	---	---	---	---	---	---
T-1,2-DICHLOROETHENE	---	---	---	---	---	---	---	---	---
C-1,2-DICHLOROETHENE	---	1.6	---	---	---	---	---	---	---
CHLOROFORM	---	1.5	---	---	117	125	29.2	---	---
1,1,1-TRICHLOROETHANE	---	---	---	---	---	---	---	---	---
CARBON TETRACHLORIDE	---	---	---	---	---	---	---	---	---
BENZENE	---	---	---	---	12.4	13.6	4.2	4.1	---
1,2-DICHLOROETHANE	---	---	---	---	---	---	---	---	---
TRICHLOROETHENE	---	---	---	---	---	---	---	---	---
TOLUENE	1.4	---	---	---	1.1	1.1	---	---	---
TETRACHLOROETHENE	2.0	---	---	---	1.1	1.3	---	---	---
CHLOROBENZENE	---	---	---	---	1.6	1.6	---	---	---
ETHYLBENZENE	1.4	2.0	---	1.9	10.2	10.7	5.1	---	---
m+p-XYLENE	---	---	---	---	25.4	28.4	2.1	---	---
o-XYLENE	---	---	---	---	---	---	---	---	---
BROMOFORM	---	---	---	---	---	---	---	---	---
1,3,5-TRIMETHYLBENZENE	2.7 *	1.4 *	---	1.6 *	28.1	29.0	1.8 *	2.3 *	---
1,2,4-TRIMETHYLBENZENE	1.6 *	1.1 *	---	1.0 *	18.8	19.6	---	1.5 *	---

Table 2. Quantitation Report for S.R. # SF-0-77 from Battle Creek, MI.

Concentration = ppb

Compound	89ESMP9S	89ESMP10S	89ESMP10D	89ESMP11S	89ESMP11D	89ESMP12S	89ESMP12S Lab Dup	89ESMP12D	89ESMP13S	89ESMP13S Field Dup
VINYL CHLORIDE	--	--	--	--	--	--	--	--	--	--
1,1-DICHLOROETHENE	--	--	--	--	--	--	--	--	--	--
T-1,2-DICHLOROETHENE	--	1.0	--	--	--	--	--	--	--	--
C-1,2-DICHLOROETHENE	--	--	--	--	--	--	--	--	--	--
CHLOROFORM	--	--	--	--	--	--	--	--	--	--
1,1,1-TRICHLOROETHANE	--	--	--	--	--	--	--	--	--	--
CARBON TETRACHLORIDE	--	--	--	--	--	--	--	--	--	--
BENZENE	--	2.0	--	2.0	--	--	--	--	--	--
1,2-DICHLOROETHANE	--	--	--	--	--	--	--	--	--	--
TRICHLOROETHENE	--	2.3	--	2.0	2.2	2.3	2.3	--	--	--
TOLUENE	--	--	--	--	1.0	1.0	1.0	1.0	--	1.0
TETRACHLOROETHENE	--	--	--	--	--	--	--	--	--	--
CHLOROBENZENE	--	--	--	--	--	--	--	--	--	--
ETHYLBENZENE	3.2	5.8	--	--	--	--	--	--	--	--
m+p-XYLENE	--	10.4	--	2.2	--	--	--	1.2	--	1.0
o-XYLENE	--	3.3	--	--	--	--	--	--	--	--
BROMOFORM	--	--	--	--	--	--	--	--	--	--
1,3,5-TRIMETHYLBENZENE	--	35.8	1.0	1.1	1.0	1.0	1.0	1.0	--	1.0
1,2,4-TRIMETHYLBENZENE	1.6 *	4.8 *	1.0 *	1.8 *	1.0 *	1.0 *	1.1 *	1.0 *	1.0 *	1.3 *
1,2,3-TRIMETHYLBENZENE	1.2 *	16.9	1.0 *	1.3 *	1.0 *	1.0 *	1.0 *	1.0 *	1.0 *	1.4 *

Compound	89BC3MW1	89BC3MW1 Field Dup	89BC3MW2	89BC3MW3	89BC3MW4	89BC3MW5	89BC3MW6	89BC3MW6 Lab Dup	89BC5MW1	Vent Well at FT-3
VINYL CHLORIDE	--	--	--	--	--	--	--	--	--	--
1,1-DICHLOROETHENE	--	--	--	--	--	--	--	--	--	1.3
T-1,2-DICHLOROETHENE	--	--	--	--	--	--	--	--	--	--
C-1,2-DICHLOROETHENE	--	--	9.8	--	--	--	--	--	--	8.0
CHLOROFORM	--	--	--	--	--	--	--	--	--	1410
1,1,1-TRICHLOROETHANE	--	--	--	--	--	--	--	--	--	--
CARBON TETRACHLORIDE	--	--	--	--	--	--	--	--	--	--
BENZENE	--	--	1.6	--	--	--	--	--	--	976
1,2-DICHLOROETHANE	--	--	--	--	--	--	--	--	--	--
TRICHLOROETHENE	--	--	--	--	--	--	--	--	--	--
TOLUENE	--	--	--	--	--	--	--	--	--	1500
TETRACHLOROETHENE	--	--	5.5	1.1	1.1	--	--	--	1.0	1.0
CHLOROBENZENE	--	--	12.8	--	--	--	--	--	--	159
ETHYLBENZENE	--	--	1.0	--	--	--	--	--	1.0	918
m+p-XYLENE	--	--	3.0	--	--	--	--	--	--	601
o-XYLENE	--	--	15.4	--	--	--	--	--	--	99
BROMOFORM	--	--	9.5	--	--	--	--	--	--	--
1,3,5-TRIMETHYLBENZENE	1.0	--	--	--	--	--	--	--	--	236
1,2,4-TRIMETHYLBENZENE	1.3 *	1.0 *	1.0 *	1.0 *	1.0 *	1.0 *	1.0 *	1.0 *	1.0 *	188
1,2,3-TRIMETHYLBENZENE	1.0 *	1.0 *	1.0 *	1.0 *	1.0 *	--	--	1.0 *	--	--

Table 3. Quantitation Report for S.... # SF-0-77 from Battle Creek, MI.

Concentration = ppb

Compound	QC0901C 200 ppb	QC0901D 500 ppb	QC0901E 20 ppb	QC0901F 50 ppb	QC0901G 200 ppb	QC0901H 500 ppb	QC0901I 20 ppb	QC0901J 50 ppb	QC0901K 200 ppb	QC0901L 500 ppb
VINYL CHLORIDE	188	--	18.4	--	193	--	18.4	--	193	--
1,1-DICHLOROETHENE	201	--	20.1	--	203	--	20.4	--	186	--
T-1,2-DICHLOROETHENE	197	--	22.4	--	194	--	22.7	--	188	--
C-1,2-DICHLOROETHENE	209	--	21.0	--	190	--	21.5	--	201	--
CHLOROFORM	--	--	--	--	--	--	--	--	--	--
1,1,1-TRICHLOROETHANE	217	--	21.1	--	218	--	21.6	--	219	--
CARBON TETRACHLORIDE	211	--	19.5	--	--	--	19.7	--	209	--
BENZENE	--	507	--	49.8	--	498	--	50.9	--	518
1,2-DICHLOROETHANE	225	--	19.9	--	186	--	19.4	--	198	--
TRICHLOROETHENE	206	--	22.8	--	206	--	23.4	--	204	--
TOLUENE	203	491	20.7	46.8	191	474	20.9	47.9	179	484
TETRACHLOROETHENE	210	--	19.7	--	215	--	20.1	--	198	--
CHLOROBENZENE	--	--	--	--	--	--	--	--	--	--
ETHYLBENZENE	--	491	--	45.3	--	480	--	47.0	--	472
m+p-XYLENE	--	987 ^	--	91.4 #	--	989 ^	--	86.5 #	--	979
o-XYLENE	--	485	--	47.9	--	481	--	48.8	--	481
BROMOFORM	--	--	--	--	--	--	--	--	--	--
1,3,5-TRIMETHYLBENZENE	1.0	476	1.1	47.1	--	498	--	47.3	--	486
1,2,4-TRIMETHYLBENZENE	1.0	458	1.0	45.7	1.0	468	1.0	44.8	1.0	448
1,2,3-TRIMETHYLBENZENE	--	474	--	47.7	--	480	1.0	47.4	--	474

Compound	QC0901M 20 ppb	QC0901N 50 ppb	QC0901O 200 ppb	QC0901P 500 ppb	QC0901Q 20 ppb	QC0901R 50 ppb	BL0901A	BL0901B
VINYL CHLORIDE	20.0	--	198	--	20.0	--	--	--
1,1-DICHLOROETHENE	21.9	--	206	--	21.6	--	--	--
T-1,2-DICHLOROETHENE	24.0	--	193	--	22.8	--	--	--
C-1,2-DICHLOROETHENE	20.2	--	192	--	19.8	--	--	--
CHLOROFORM	--	--	--	--	--	--	--	--
1,1,1-TRICHLOROETHANE	22.6	--	218	--	22.3	--	--	--
CARBON TETRACHLORIDE	20.9	--	--	--	20.6	--	--	--
BENZENE	--	53.0	--	518	--	52.8	--	--
1,2-DICHLOROETHANE	16.9	--	192	--	16.8	--	--	--
TRICHLOROETHENE	23.7	--	200	--	23.1	--	--	--
TOLUENE	21.5	50.5	190	483	20.9	49.6	--	--
TETRACHLOROETHENE	21.0	--	208	--	20.0	--	--	--
CHLOROBENZENE	--	--	--	--	--	--	--	--
ETHYLBENZENE	--	48.8	--	483	--	48.0	--	--
m+p-XYLENE	--	91.1 #	--	982 ^	--	90.5 #	--	--
o-XYLENE	--	49.9	--	474	--	49.3	--	--
BROMOFORM	--	--	--	--	--	--	--	--
1,3,5-TRIMETHYLBENZENE	1.0	48.9	--	501	--	48.1	--	1.0
1,2,4-TRIMETHYLBENZENE	--	46.4	1.0	451	1.0	45.4	1.0	1.0
1,2,3-TRIMETHYLBENZENE	--	47.8	--	470	1.0	48.3	1.0	--

MAN~~AGEMENT~~
TECH~~NOLOGY~~

Ref: 94-JH11/vg

September 16, 1994

Dr. Don Kampbell
R.S. Kerr Environmental Research Lab
U.S. Environmental Protection Agency
P.O. Box 1198
Ada, OK 74820

THRU: S.A. Vandegrift ᔓ4√

Dear Don:

Attached are TOC results for a set of 24 soil samples submitted to ManTech August 16, 1994 under Service Request #SF-0-77. TOC determinations were begun August 29, 1994 and completed September 16, 1994 using RSKSOP-102 and RSKSOP-120.

A Leco standard soil and a known AQC sample were analyzed with your samples for quality control.

If you have any questions concerning this data, please feel free to contact me.

Sincerely,

Jeff Hickerson

Jeff Hickerson

xc: R.L. Cosby
    J.L. Seeley *jls*

ManTech Environmental Research Services Corporation

R.S. Kerr Environmental Research Laboratory, P.O. Box 1198, 919 Kerr Research Drive
Ada, Oklahoma 74821-1198   405-436-8660   FAX 405-436-8501

BATTLE CREEK SOIL SAMPLE... FOR TOC (SR# SF-0-77)

SAMPLE	SOIL FILT %OC	SOLIDS %OC	TOTAL SOIL %TOC	MEAN %TOC
ESSB-1 26'-26.5' #1	0.023	7.588	7.611	
ESSB-1 26'-26.5' #2	0.045	6.881	6.926	7.270
ESSB-1 27.5'-28' #1	0.067	0.081	0.148	
ESSB-1 27.5'-28' #2	0.070	0.069	0.139	0.144
ESSB-2 14' #1	0.008	0.144	0.152	
ESSB-2 14' #2	0.006	0.137	0.143	0.148
ESSB-2 2' #1	0.023	0.440	0.463	
ESSB-2 2' #2	0.027	0.414	0.441	0.452
ESSB-2 21.75'-22.5' #1	0.014	0.043	0.057	0.070
ESSB-2 21.75'-22.5' #2	0.042	0.041	0.083	
ESSB-3 2'-2.5' #1	0.027	0.073	0.100	0.088
ESSB-3 2'-2.5' #2	0.027	0.050	0.077	
ESSB-3 14'-14.5' #1	0.020	0.029	0.049	0.053
ESSB-3 14'-14.5' #2	0.021	0.036	0.057	
ESSB-3 22'-22.5' #1	0.009	0.046	0.055	0.058
ESSB-3 22'-22.5' #2	0.011	0.049	0.060	
ESSB-4 2'-2.5' #1	0.064	0.622	0.686	0.619
ESSB-4 2'-2.5' #2	0.049	0.439	0.488	
ESSB-4 2'-2.5' #3	0.053	0.585	0.638	
ESSB-4 14'-14.5' #1	0.012	0.128	0.140	0.143
ESSB-4 14'-14.5' #2	0.014	0.132	0.146	
ESSB-4 21.5'-22' #1	0.016	0.129	0.145	0.159
ESSB-4 21.5'-22' #2	0.025	0.165	0.190	
ESSB-4 21.5'-22' #3	0.019	0.123	0.142	
ESSB-5 2'-2.5' #1	0.067	0.561	0.628	0.526
ESSB-5 2'-2.5' #2	0.047	0.430	0.477	
ESSB-5 2'-2.5' #3	0.045	0.428	0.473	
ESSB-5 14'-14.5' #1	0.027	0.316	0.343	0.324
ESSB-5 14'-14.5' #2	0.024	0.280	0.304	
ESSB-5 21'-21.5' #1	0.009	0.036	0.045	0.044
ESSB-5 21'-21.5' #2	0.009	0.034	0.043	

SAMPLE	SOIL FILT %OC	SOLIDS %OC	TOTAL SOIL %TOC	MEAN %TOC
ESSB-6 2.75'-3.5' #1	0.046	0.626	0.672	0.671
ESSB-6 2.75'-3.5' #2	0.042	0.628	0.670	
ESSB-6 4'-4.5' #1	0.047	0.717	0.764	0.603
ESSB-6 4'-4.5' #2	0.042	0.484	0.526	
ESSB-6 4'-4.5' #3	0.049	0.470	0.519	
ESSB-6 13.5'-14.25' #1	0.011	0.091	0.102	0.093
ESSB-6 13.5'-14.25' #2	0.009	0.074	0.083	
ESSB-6 21'-21.5' #1	0.008	0.072	0.080	0.082
ESSB-6 21'-21.5' #2	0.009	0.075	0.084	
ESSB-6 27'-27.5' #1	0.005	0.083	0.088	0.087
ESSB-6 27'-27.5' #2	0.007	0.078	0.085	
ESSB-7 10'-10.5' #1	0.008	0.049	0.057	0.069
ESSB-7 10'-10.5' #2	0.011	0.071	0.082	
ESSB-8 10'-10.5' #1	0.004	0.071	0.075	0.098
ESSB-8 10'-10.5' #2	0.004	0.136	0.140	
ESSB-8 10'-10.5' #3	0.012	0.068	0.080	
ESSB-9 10'-10.5' #1	0.008	0.047	0.055	0.055
ESSB-9 10'-10.5' #2	0.007	0.047	0.054	
ESSB-10 5'-5.5' #1	0.010	0.032	0.042	0.041
ESSB-10 5'-5.5' #2	0.009	0.030	0.039	
ESSB-10 10'-10.5' #1	0.002	0.029	0.031	0.028
ESSB-10 10'-10.5' #2	0.004	0.022	0.026	
LECO		1.011		
		0.996		
		1.007		
		1.005		
WPO32-I	45.0 MG/L			
	45.4 MG/L			
	45.7 MG/L			
	43.1 MG/L			
	43.1 MG/L			
	43.2 MG/L			

TRUE VALUES: LECO STD SOIL = 1.00 +/- 0.04% C
WPO32-I = 44.0 MG/L

MAN*AGEMENT*
TECH*NOLOGY*

                                          Ref: 94-LP82/vg
                                                 94-MW88/vg

                                          September 8, 1994

Dr. Don Kampbell
R.S. Kerr Environmental Research Lab
U.S. Environmental Protection Agency
Post Office Box 1198
Ada, OK 74820

THRU: S.A. Vandegrift

Dear Don:

     Attached are the results of 33 Battle Creek, MI samples
submitted to ManTech as part of S.R. #SF-0-77 Mod. 1. The samples
were received on August 24, 1994, and analyzed August 25 and 26,
1994. The methods used for analysis were EPA Methods 353.1, 310.1,
and Water's capillary electrophoresis method N-601. Quality
assurance measures performed on this set of samples included
spikes, duplicates, known AQC samples and blanks.

     If you have any questions concerning these results please feel
free to contact us.

                                      Sincerely,

                                      Lynda Pennington

                                      Mark White

xc: R.L. Cosby
     J.L. Seeley

ManTech Environmental Research Services Corporation

R.S. Kerr Environmental Research Laboratory, P.O. Box 1198, 919 Kerr Research Drive
Ada, Oklahoma 74821-1198   405-436-8660   FAX 405-436-8501

Sample		mg/L Cl-	mg/L SO4=	mg/L Total Alkalinity (as CaCO3)	µS/cm Conductivity	mg/L NO2- + NO3-(N)
84E	SMP-1S	2.64	2.70	670	917	<.05
84E	SMP-1D	1.77	7.96	200	454	2.49
89E	SMP-2S	1.51	5.60	252	532	1.27
89E	SMP-2D	2.05	14.7	212	466	1.24
89E	SMP-3S	6.68	12.8	166	399	1.48
89E	SMP-3S Dup	6.79	12.8	---	---	----
89E	SMP-3D	2.07	8.59	186	409	2.24
89E	SMP-3DD	5.57	23.7	264	564	<.05
89E	SMP-4S	3.65	11.7	158	390	3.42
89E	SMP-4S Dup	---	---	---	---	3.40
89E	SMP-4D	1.96	10.4	212	455	2.00
89E	SMP-5S	12.8	9.70	132	340	0.31
89E	SMP-5D	2.54	8.52	200	438	1.98
89E	SMP-5D Dup	---	---	200	436	----
89E	SMP-6S	6.61	12.3	226	513	2.23
89E	SMP-6D	7.36	13.1	232	518	2.50
89E	SMP-7S	7.21	6.45	274	600	1.34
89E	SMP-7S Dup	7.12	6.36	---	---	----
89E	SMP-7D	2.72	12.0	232	480	.06
89E	SMP-7D Dup	---	---	---	---	.05
89E	SMP-8S	1.86	13.2	286	595	1.31
89E	SMP-8D	2.85	17.9	228	490	0.52
89E	SMP-9S	2.44	1.82	284	551	.06
89E	SMP-10S	4.54	3.56	282	626	<.05
89E	SMP-10S Dup	4.48	3.45	---	---	----
89E	SMP-10D	3.25	13.2	318	467	*
89E	SMP-10D Dup	---	---	320	467	---
89E	SMP-11S	11.9	15.8	210	479	*
89E	SMP-11D	1.80	15.6	212	412	*
89E	SMP-12S	5.21	12.7	204	467	*
89E	SMP-12D	5.05	27.3	260	547	*
89E	SMP-13S	2.72	8.73	302	588	*
89	BCJ-MW1	4.64	21.8	254	528	<.05

* = No fixed samples were received.

Sample	mg/L Cl⁻	mg/L SO₄⁻	mg/L Total Alkalinity (as CaCO₃)	µS/cm Conductivity	mg/L NO₂⁻ + NO₃⁻(N)
89 BC3-MW2	2.14	15.0	212	460	<.05
89 BC3-MW3	1.77	9.81	174	421	1.00
89 BC3-MW4	2.90	22.8	224	495	0.06
89 BC3-MW5	1.65	11.1	194	440	2.13
89 BC3-MW6	4.70	22.9	248	545	0.05
89 BC5-MW1	2.24	12.7	260	565	1.95
89 BC5-MW1 Dup	2.26	12.8	----	----	----
Vent Well @ FT-3	6.00	7.50	492	1030	<.05
Vent Well @ FT-3 Dup	5.86	7.42	----	----	----
Blank	<.5	<.5	----	----	<.05
WP032	107	73.9	----	----	2.69
WP032 T.V.	108	73.1	----	----	2.67
Spike Recovery	108	75.0	----	----	2.81
	97%	99%			98%
	99%	101%			94%

MANAGEMENT
TECHNOLOGY

Ref: 94-DK20/vg

September 12, 1994

Dr. Don Kampbell
R.S. Kerr Environmental Research Lab
U.S. Environmental Protection Agency
P.O. Box 1198
Ada, OK 74820

THRU: S.A. Vandegrift SAV

Dear Don:

    This report contains the results of my GC/MSD analysis of
methylene chloride extracts of core samples from Battle Creek AFB
for quantitation of benzene, trichloroethylene (TCE),
tetrachloroethylene (PCE), toluene, ethylbenzene (EB), p-Xylene
(p-X), m-Xylene (m-X), o-Xylene (o-X), 1,3,5-trimethylbenzene
(1,3,5-TMB), 1,2,4-trimethylbenzene (1,2,4-TMB), 1,2,3-
trimethylbenzene (1,2,3-TMB), 1,3-dichlorobenzene (1,3-DCB), 1,4-
dichlorobenzene (1,4-DCB), 1,2-dichlorobenzene (1,2-DCB),
naphthalene (Naph.), 2-methylnaphthalene (2-MeNaph.) and 1-
methylnaphthalene (1-MeNaph.) performed under Service Request
#SF-0-77. cis-Dichloroethene and trans-dichloroethene were not
quantified because they coeluted with the methylene chloride
extraction solvent. Vinyl chloride eluted prior to the solvent
peak and was monitored using ions 62 and 64. No vinyl chloride
was detected.

    The analytical method was a modification of RSKSOP-124.
Cool (38°C) on-column injection (0.5 μl) was used with electronic
pressure control set for a constant flow of 0.9 ml/min. A 30M X
0.25 mm Restek Stabilwax (Crossbonded Carbowax-PEG, 0.5 μm film)
capillary GC column with 9 inch long X 0.53 mm ID uncoated
capillary precolumn was used. Quantitation was based on
calibration curves of selected target ions (1 to 4 ions , total
area) for each compound. Use of multiple ions for each compound
also aided in verifying peak purity. A high level (1.6-250
μg/ml) and low level (0.032-2 μg/ml) calibration curve was
applied to each sample for quantitation. Complete reports
detailing the acquisition method and calibration curves have been
recorded. The samples were extracted by Mark Blankenship on
August 24, 1994 and analyzed by GC/MSD on September 2-3, 1994.
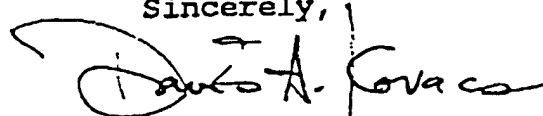
ManTech Environmental Research Services Corporation

R.S. Kerr Environmental Research Laboratory, P.O. Box 1198, 919 Kerr Research Drive
Ada, Oklahoma 74821-1198   405-436-8660   FAX 405-436-8501

If I can be of further assistance, please feel free to contact me.

Sincerely,

David A. Kovacs

xc: R.L. Cosby
    J.L. Seeley
    G. Smith

Units: mg/kg

GC/MSD of Battle Creek...FB MeCl2 extracted cores

SR...0-77 Dr. Kampbell

SAMPLE NAME	Benzene	TCE	PCE	Toluene	EB	p-X	m-X	o-X
ESS-B1,26-26.5'	BLQ	2.88E-02	1.36E+00	BLQ	ND	ND	ND	ND
ESS-B1,27.5-28'	ND	ND	9.06E-02	BLQ	ND	ND	ND	ND
ESS-B2,14'	ND	ND	1.91E-02	BLQ	ND	ND	ND	ND
ESS-B2,20'	BLQ	ND	3.53E-02	BLQ	ND	BLQ	ND	BLQ
ESS-B2,21.76-22.5'	ND	ND	6.21E-02	BLQ	ND	ND	ND	ND
ESS-B3,2-2.5'	ND	ND	1.24E-01	BLQ	ND	ND	ND	ND
ESS-B3,2-2.5'(DUP.)	ND	ND	1.33E-01	BLQ	ND	ND	ND	ND
ESS-B3,14-14.5'	ND	ND	6.04E-02	BLQ	ND	ND	ND	ND
ESS-B3,22-22.5'	ND	ND	6.94E-02	BLQ	ND	BLQ	ND	BLQ
ESS-B4,2-2.5'	ND	ND	9.34E-02	BLQ	ND	ND	ND	ND
ESS-B4,14-14.5'	ND	ND	2.10E-02	BLQ	ND	ND	ND	BLQ
ESS-B4,21.5-22'	ND	ND	2.72E-02	BLQ	ND	ND	ND	BLQ
ESS-B5,2-2.5'	ND	ND	2.43E-02	BLQ	ND	ND	ND	ND
ESS-B5,14-14.5'	ND	ND	3.09E-02	1.54E-02	ND	BLQ	ND	BLQ
ESS-B5,21-21.5'	ND	ND	BLQ	BLQ	ND	ND	ND	ND
ESS-B6,2.75-3.5'	ND	ND	2.16E-02	BLQ	BLQ	BLQ	BLQ	BLQ
ESS-B6,4-4.5'	1.39E-02	BLQ	3.40E-02	1.56E-01	BLQ	2.22E-02	4.30E-02	1.44E-02
ESS-B6,13.5-14.25'	ND	ND	2.29E-02	BLQ	ND	ND	ND	ND
ESS-B6,21-21.5'	ND	ND	3.10E-02	BLQ	ND	BLQ	ND	1.63E-02
ESS-B6,21-21.5'(DUP)	BLQ	BLQ	2.26E-02	BLQ	BLQ	3.16E-02	4.39E-02	9.22E-02
ESS-B6,27-27.5'	2.03E-02	BLQ	2.66E-02	3.07E-02	7.31E-01	1.69E+00	2.48E+00	3.05E-02
ESS-B7,10-10.5'	ND	ND	4.01E-02	BLQ	ND	ND	ND	ND
ESS-B8,10-10.5'	BLQ	ND	4.65E-02	BLQ	ND	ND	ND	BLQ
ESS-B9,10-10.5'	ND	ND	1.80E-02	BLQ	ND	ND	ND	ND
ESS-B10,5-5.5'	ND	ND	8.07E-02	BLQ	ND	ND	ND	ND
ESS-B10,18.5-19'	ND	ND	3.22E-02	BLQ	ND	ND	ND	ND

Quality Control Summary

	Benzene	TCE	PCE	Toluene	EB	p-X	m-X	o-X
Methylene Chloride	ND	ND	ND	ND	ND	ND	ND	ND
Methylene Chloride	ND	ND	ND	ND	ND	ND	ND	ND
Methylene Chloride	ND	ND	ND	ND	ND	ND	ND	ND
Method Blank#1 (ug/ml)	ND	ND	ND	ND	ND	ND	ND	ND
Method Blank#2 (ug/ml)	ND	ND	ND	ND	ND	ND	ND	ND
0.32-0.4 ug/ml	3.10E-01	3.09E-01	3.10E-01	3.10E-01	3.13E-01	3.16E-01	3.11E-01	3.19E-01

BLQ < 0.032 ug/ml

Analyst: David A. Kovacs

Printed: 9/11/94 1 of 4

GC/MSD of Battle ... AFB MeCl2 extracted cores

...0-77 Dr. Kampbell   mg/kg

SAMPLE NAME	1,3,5-TMB	1,2,4-TMB	1,2,3-TMB	1,3-DCB	1,4-DCB	1,2-DCB	Naph.	2-MeNaph.	1-MeNaph.
ESS-B1,26-26.5'	ND	ND	ND	ND	ND	ND	ND	BLQ	BLQ
ESS-B1,27.5-28'	ND	ND	ND	ND	ND	ND	ND	BLQ	ND
ESS-B2,14'	ND	ND	BLQ	ND	ND	ND	ND	ND	ND
ESS-B2,20'	BLQ	BLQ	BLQ	ND	ND	ND	ND	BLQ	ND
ESS-B2,21.76-22.5'	BLQ	BLQ	ND	ND	ND	ND	ND	BLQ	ND
ESS-B3,2-2.5'	ND	ND	ND	ND	ND	ND	ND	ND	ND
ESS-B3,2-2.5'(DUP.)	ND	ND	ND	ND	ND	ND	ND	BLQ	ND
ESS-B3,14-14.5'	ND	ND	ND	ND	ND	ND	ND	BLQ	ND
ESS-B3,22-22.5'	ND	BLQ	ND	ND	ND	ND	ND	BLQ	ND
ESS-B4,2-2.5'	ND	BLQ	ND	ND	ND	ND	ND	ND	ND
ESS-B4,14-14.5'	ND	ND	ND	ND	ND	ND	ND	ND	ND
ESS-B4,21.5-22'	BLQ	BLQ	ND	ND	ND	ND	ND	BLQ	ND
ESS-B5,2-2.5'	ND	ND	ND	ND	ND	ND	ND	ND	ND
ESS-B6,14-14.5'	ND	BLQ	BLQ	ND	ND	ND	ND	BLQ	BLQ
ESS-B6,21-21.5'	ND	ND	ND	ND	ND	ND	ND	ND	ND
ESS-B6,2.75-3.5'	BLQ	BLQ	BLQ	ND	ND	ND	BLQ	BLQ	BLQ
ESS-B6,4-4.5'	BLQ	1.35E-02	BLQ	ND	ND	ND	ND	BLQ	BLQ
ESS-B6,13.5-14.25'	ND	ND	ND	ND	ND	ND	ND	BLQ	ND
ESS-B6,21-21.5'	3.12E-02	2.42E-02	6.31E-02	ND	ND	ND	BLQ	1.71E-02	BLQ
ESS-B6,21-21.5'(DUP)	2.99E-01	2.86E-01	3.91E-01	ND	ND	ND	1.33E-02	1.19E-01	1.08E-01
ESS-B6,27-27.5'	6.13E+00	1.06E+01	6.97E+00	ND	ND	ND	1.69E+00	4.65E+00	3.69E+00
ESS-B7,10-10.5'	ND	ND	ND	ND	ND	ND	ND	BLQ	ND
ESS-B8,10-10.5'	ND	BLQ	ND	ND	ND	ND	ND	BLQ	ND
ESS-B9,10-10.5'	ND	ND	ND	ND	ND	ND	ND	BLQ	ND
ESS-B10,5-5.5'	ND	ND	ND	ND	ND	ND	ND	BLQ	ND
ESS-B10,18.5-19'	ND	ND	ND	ND	ND	ND	ND	BLQ	ND
0.32-0.4 ug/ml	3.14E-01	3.23E-01	3.22E-01	3.22E-01	3.32E-01	3.35E-01	3.98E-01	3.81E-01	3.95E-01

Quality Control Summary

	1,3,5-TMB	1,2,4-TMB	1,2,3-TMB	1,3-DCB	1,4-DCB	1,2-DCB	Naph.	2-MeNaph.	1-MeNaph.
Methylene Chloride	ND	ND	ND	ND	ND	ND	ND	BLQ	ND
Methylene Chloride	ND	ND	ND	ND	ND	ND	ND	BLQ	ND
Methylene Chloride	ND	ND	ND	ND	ND	ND	ND	BLQ	ND
Meth.Blk#1(ug/ml)	ND	ND	ND	ND	ND	ND	ND	BLQ	ND
Meth.Blk#2(ug/ml)	ND	ND	ND	ND	ND	ND	ND	BLQ	ND

BLQ < 0.032 ug/ml

Analyst: David A. Kovacs

Printed: 9/11/94 2 of 4

GC/MSD of Battle C... AFB MeCl2 extracted cores

F-0-77 Dr. Kampbell

= mg/kg

SAMPLE NAME	Benzene	TCE	PCE	Toluene	EB	p-X	m-X	o-X
0.32-0.40 ug/ml	3.29E-01	3.30E-01	3.30E-01	3.31E-01	3.27E-01	3.25E-01	3.06E-01	3.21E-01
1.6-2.0 ug/ml	1.74E+00	1.71E+00	1.71E+00	1.72E+00	1.72E+00	1.72E+00	1.72E+00	1.72E+00
1.6-2.0 ug/ml	1.47E+00	1.49E+00	1.49E+00	1.48E+00	1.47E+00	1.48E+00	1.47E+00	1.48E+00
8-10 ug/ml	7.58E+00	7.39E+00	7.63E+00	7.75E+00	7.63E+00	7.56E+00	7.71E+00	7.59E+00
40-50 ug/ml	4.23E+01	4.32E+01	4.32E+01	4.40E+01	4.32E+01	4.32E+01	4.36E+01	4.32E+01
40-50 ug/ml	3.88E+01	3.93E+01	3.95E+01	4.08E+01	3.97E+01	3.97E+01	4.01E+01	3.95E+01
40-50 ug/ml	3.72E+01	3.66E+01	3.76E+01	3.91E+01	3.81E+01	3.85E+01	3.62E+01	3.88E+01
200-260 ug/ml	1.90E+02	1.92E+02	1.92E+02	1.80E+02	1.92E+02	1.90E+02	1.89E+02	1.90E+02
200-260 ug/ml	2.00E+02	2.02E+02	2.03E+02	1.89E+02	2.04E+02	2.05E+02	2.03E+02	2.05E+02
10/100 ug/ml QC Mix 1	N/A	N/A	N/A	9.14E+00	N/A	N/A	N/A	N/A
10 ug/ml QC Mix 2	9.30E+00	9.68E+00	N/A	9.67E+00	9.22E+00	9.02E+00	9.05E+00	9.08E+00
10 ug/ml QC Mix 3	N/A	N/A	N/A	1.01E+01	N/A	N/A	N/A	N/A
10 ug/ml QC Mix 4	9.43E+00	N/A	N/A	9.77E+00	8.11E+00	9.41E+00	9.00E+00	9.82E+00

Analyst: David A. Kovacs

BLQ < 0.032 ug/ml

SEP-28-1994 15:33   USEPA RSKERL-ADA SSB/SPB   405 436 6703   P.12

GC/MSD of Battle C... AB MeCl2 extracted cores — Dr. Kampbell — mg/Kg

SAMPLE NAME	1,3,5-TMB	1,2,4-TMB	1,2,3-TMB	1,3-DCB	1,4-DCB	1,2-DCB	Naph.	2-MeNaph.	1-MeNaph.
0.32-0.40 ug/ml	3.26E-01	3.17E-01	3.20E-01	3.18E-01	3.09E-01	3.05E-01	4.06E-01	4.18E-01	4.05E-01
1.6-2.0 ug/ml	1.75E+00	1.74E+00	1.73E+00	1.74E+00	1.71E+00	1.71E+00	2.13E+00	2.18E+00	2.16E+00
1.6-2.0 ug/ml	1.45E+00	1.46E+00	1.47E+00	1.46E+00	1.49E+00	1.48E+00	1.86E+00	1.83E+00	1.86E+00
8-10 ug/ml	7.66E+00	7.73E+00	7.72E+00	7.32E+00	7.33E+00	7.30E+00	9.44E+00	9.57E+00	9.47E+00
40-50 ug/ml	4.32E+01	4.39E+01	4.43E+01	4.28E+01	4.27E+01	4.13E+01	6.48E+01	6.54E+01	6.34E+01
40-50 ug/ml	3.98E+01	4.06E+01	4.06E+01	3.94E+01	3.94E+01	3.83E+01	5.13E+01	5.14E+01	4.97E+01
40-50 ug/ml	3.89E+01	3.88E+01	4.00E+01	3.90E+01	3.94E+01	3.82E+01	4.94E+01	4.87E+01	4.87E+01
200-250 ug/ml	1.90E+02	1.91E+02	1.91E+02	1.91E+02	1.90E+02	1.90E+02	2.49E+02	2.50E+02	2.42E+02
200-250 ug/ml	2.08E+02	2.05E+02	2.06E+02	2.06E+02	2.08E+02	2.07E+02	2.58E+02	2.59E+02	2.61E+02
10/100 ug/ml QC Mix 1	N/A	N/A	N/A	N/A	N/A	9.20E+00	9.93E+01	N/A	N/A
10 ug/ml QC Mix 2	9.05E+00	8.01E+00	9.04E+00	9.12E+00	N/A	9.39E+00	N/A	N/A	N/A
10 ug/ml QC Mix 3	N/A	N/A	N/A	N/A	N/A	9.01E+00	9.10E+00	N/A	N/A
10 ug/ml QC Mix 4	9.84E+00	9.91E+00	9.93E+00	N/A	N/A	N/A	N/A	N/A	N/A

Analyst: David A. Kovacs

BLQ < 0.032 ug/ml

Printed: 8/11/94 4 of 4

**MANAGEMENT
TECHNOLOGY**

Ref: 94-BN47/vg

September 9, 1994

Dr. Don Kampbell
R.S. Kerr Environmental Research Lab
U.S. Environmental Protection Agency
Post Office Box 1198
Ada, OK 74820

THRU: S.A. Vandegrift

Dear Don:

    Please find attached results for methane, ethylene, and ethane on Battle Creek, MI samples as per Service Request # SF-0-77. Samples were received on August 23, and analyzed August 24-25, 1994. Samples were prepared as described in the paper "Dissolved Oxygen and Methane in Water by a GC Headspace Equilibration Technique", by Kampbell et al., in International Journal of Environmental Analytical Chemistry, Volume 36, pp. 249-257. Analysis and calculations were performed as per RSKSOP-147.

    If you have any questions, please feel free to see me.

Sincerely,

Bryan Newell

Bryan Newell

xc: R.L. Cosby
    J.L. Seeley
    J.T. Wilson

ManTech Environmental Research Services Corporation

R.S. Kerr Environmental Research Laboratory, P.O. Box 1198, 919 Kerr Research Drive
Ada, Oklahoma 74821-1198 405-436-8660 FAX 405-436-8501

SF-0-77A.XLS

ANALYZED 8/24/94

SAMPLE	METHANE	ETHYLENE	ETHANE
LAB BLANK	BLQ	ND	ND
89ESMP-10D	0.003	ND	0.001
89ESMP-11S	BLQ	ND	ND
89ESMP-11D	0.002	ND	0.001
89ESMP-12S	0.002	ND	0.001
89ESMP-12D	0.003	ND	0.001
89ESMP-13S	0.003	ND	0.001
LAB BLANK	BLQ	ND	ND
84ESMP-1S	4.228	BLQ	0.019
84ESMP-1D	0.004	ND	ND
893SMP-2S	0.066	ND	BLQ
89ESMP-2D	0.003	ND	BLQ
* LAB DUP	0.003	ND	BLQ
89ESMP-3S	BLQ	ND	ND
89ESMP-3D	0.003	ND	0.001
89ESMP-3DD	0.004	ND	0.001
89ESMP-4D	0.001	ND	ND
89ESMP-4S	ND	ND	ND
89ESMP-5S	0.007	ND	0.002
89ESMP-5D	0.015	ND	0.001
89ESMP-6S	BLQ	ND	ND

ANALYZED 8/25/94

SAMPLE	METHANE	ETHYLENE	ETHANE
LAB BLANK	BLQ	ND	ND
89ESMP-6D	0.003	ND	0.001
89ESMP-7S	0.829	ND	0.004
89ESMP-7D	0.165	ND	0.002
89ESMP-8S	0.003	ND	0.001
* LAB DUP	0.003	ND	0.001
89ESMP-8D	0.002	ND	0.001
89ESMP-9S	0.157	ND	0.001
89ESMP-10S	0.614	ND	0.003
89BC3-MW1	0.002	ND	ND
89BC3-MW2	0.393	ND	0.001
89BC3-MW3	BLQ	ND	ND
89BC3-MW4	BLQ	ND	ND
89BC3-MW5	ND	ND	ND
89BC3-MW6	BLQ	ND	ND
89BC5-MW1	ND	ND	ND
VENT WELL AT FT-3	8.397	0.001	0.017
* LAB DUP	8.340	0.001	0.016

SF-0-77A.XLS

SAMPLE	METHANE	ETHYLENE	ETHANE
10 PPM CH4	10.37	ND	ND
100 PPM CH4	101.58	ND	ND
990 PPM CH4	999.84	ND	ND
1 % CH4	0.99	ND	ND
4 % CH4	4.07	ND	ND
10 % CH4	9.96	ND	ND
10 PPM C2H4	ND	10.18	ND
100 PPM C2H4	ND	99.98	ND
10 PPM C2H6	ND	ND	10.09
100 PPM C2H6	ND	ND	99.99

LOWER LIMIT OF QUANTITATION

METHANE	ETHYLENE	ETHANE
0.001	0.002	0.001

UNITS FOR THE SAMPLES ARE mg/L.

UNITS FOR THE STANDARDS CORRESPOND TO THE
UNITS IN THE SAMPLE COLUMN.

BLQ DENOTES BELOW LIMIT OF QUANTITATION.
ND DENOTES NONE DETECTED.

Method 8010 Chlorinated VOC's
Sample Report

Client Sample #	: ESSB-1(26-26.5')	Client Project #	: Battle Creek
Lab Sample #	: X93547	Lab Project #	: 94-3273
Date Sampled	: Not Specified	Matrix	: Soil
Date Received	: 8/29/94	Lab File #	: Hall0830018
Date Prepared	: 8/30/94	Method Blank	: MB083094
Date Analyzed	: 8/31/94	Dilution Factor	: 5.0

Compound	CAS #	Concentration (ug/Kg)	EDL(ug/Kg)
Dichlorodifluoromethane	75-71-8	U	1
Chloromethane	74-87-3	U	2
Vinyl Chloride	75-01-4	U	1
Bromomethane	74-83-9	U	1
Chloroethane	75-00-3	U	2.5
Trichlorofluoromethane	75-69-4	U	2
1,1-Dichloroethene	75-35-4	U	2
Dichloromethane	75-09-2	16 B	2
trans-1,2-Dichloroethene	156-60-5	U	1
1,1-Dichloroethane	75-34-3	U	1.5
Chloroform	67-66-3	3.2 B	1
1,1,1-Trichloroethane	71-55-6	5.0	1.5
1,2-Dichloroethane	107-06-2	U	1.5
Carbon Tetrachloride	56-23-5	U	0.5
Trichloroethene	79-01-6	U	1
1,2-Dichloropropane	78-87-5	U	2
Bromodichloromethane	75-27-4	U	0.5
2-Chloroethyl vinyl ether	110-75-8	U	20
cis-1,3-Dichloropropene	10061-01-5	U	2.5
trans-1,3-Dichloropropene	10061-02-6	U	2
1,1,2-Trichloroethane	79-00-5	U	1
Tetrachloroethene	127-18-4	170	1.5
Dibromochloromethane	124-48-1	U	2
Chlorobenzene	108-90-7	U	1
Bromoform	75-25-2	U	1
1,1,2,2-Tetrachloroethane	79-34-5	U	1.5
1,3-Dichlorobenzene	541-73-1	U	2
1,4-Dichlorobenzene	106-46-7	U	2
1,2-Dichlorobenzene	95-50-1	U	2

Surrogate Recovery   (1-Chloro-2-Fluoro-Benzene)   :   66%

QUALIFIERS:
U = Compound analyzed for, but not detected.
B = Compound in blank and sample. Compare blank and sample date.
EDL = Evergreen's Estimated Detection Limit.

_____   _____
Analyst   Approved

X93547 DF=5 Client #6   ESSB-1(26-26.5')

Tetrachloroethene

Surrogate

1,1,1-Trichloroethane

Chloroform

Dichloromethane

1.5e4
1.4e4
1.3e4
1.2e4
1.1e4
1.0e4
9000
8000
7000
6000

10   20   30   40   50   60

Date Run: 08-31-94

Sig. 2 in C:\HPCHEM\2\DATA\HALL0830\018R0101.D

Method 8010 Chlorinated VOC's
Sample Report

Client Sample #	: ESSB-1(27.5-28')	Client Project #	: Battle Creek
Lab Sample #	: X93549	Lab Project #	: 94-3273
Date Sampled	: Not Specified	Matrix	: Soil
Date Received	: 8/29/94	Lab File #	: Hall0830028
Date Prepared	: 8/31/94	Method Blank	: MB083194
Date Analyzed	: 8/31/94	Dilution Factor	: 1.0

Compound	CAS #	Concentration (ug/Kg)	EDL(ug/Kg)
Dichlorodifluoromethane	75-71-8	U	0.2
Chloromethane	74-87-3	U	0.4
Vinyl Chloride	75-01-4	U	0.2
Bromomethane	74-83-9	U	0.2
Chloroethane	75-00-3	U	0.3
Trichlorofluoromethane	75-69-4	U	0.4
1,1-Dichloroethene	75-35-4	U	0.4
Dichloromethane	75-09-2	5.0 B	0.4
trans-1,2-Dichloroethene	156-60-5	U	0.2
1,1-Dichloroethane	75-34-3	U	0.3
Chloroform	67-66-3	0.8 B	0.2
1,1,1-Trichloroethane	71-55-6	U	0.3
1,2-Dichloroethane	107-06-2	U	0.3
Carbon Tetrachloride	56-23-5	U	0.1
Trichloroethene	79-01-6	U	0.2
1,2-Dichloropropane	78-87-5	U	0.4
Bromodichloromethane	75-27-4	U	0.1
2-Chloroethyl vinyl ether	110-75-8	U	4.0
cis-1,3-Dichloropropene	10061-01-5	U	0.5
trans-1,3-Dichloropropene	10061-02-6	U	0.4
1,1,2-Trichloroethane	79-00-5	U	0.2
Tetrachloroethene	127-18-4	1.9	0.3
Dibromochloromethane	124-48-1	U	0.4
Chlorobenzene	108-90-7	U	0.2
Bromoform	75-25-2	U	0.2
1,1,2,2-Tetrachloroethane	79-34-5	U	0.3
1,3-Dichlorobenzene	541-73-1	U	0.4
1,4-Dichlorobenzene	106-46-7	U	0.4
1,2-Dichlorobenzene	95-50-1	U	0.4

Surrogate Recovery (1-Chloro-2-Fluoro-Benzene)   :   87%

QUALIFIERS:
U = Compound analyzed for, but not detected.
B = Compound in blank and sample. Compare blank and sample date.
EDL = Evergreen's Estimated Detection Limit.

_____
Analyst

_____
Approved

X93549 DF=1 Client # ESSB-1(27.5-28')

Surrogate

Tetrachloroethene

Chloroform

Dichloromethane

Date Run: 08-31-94
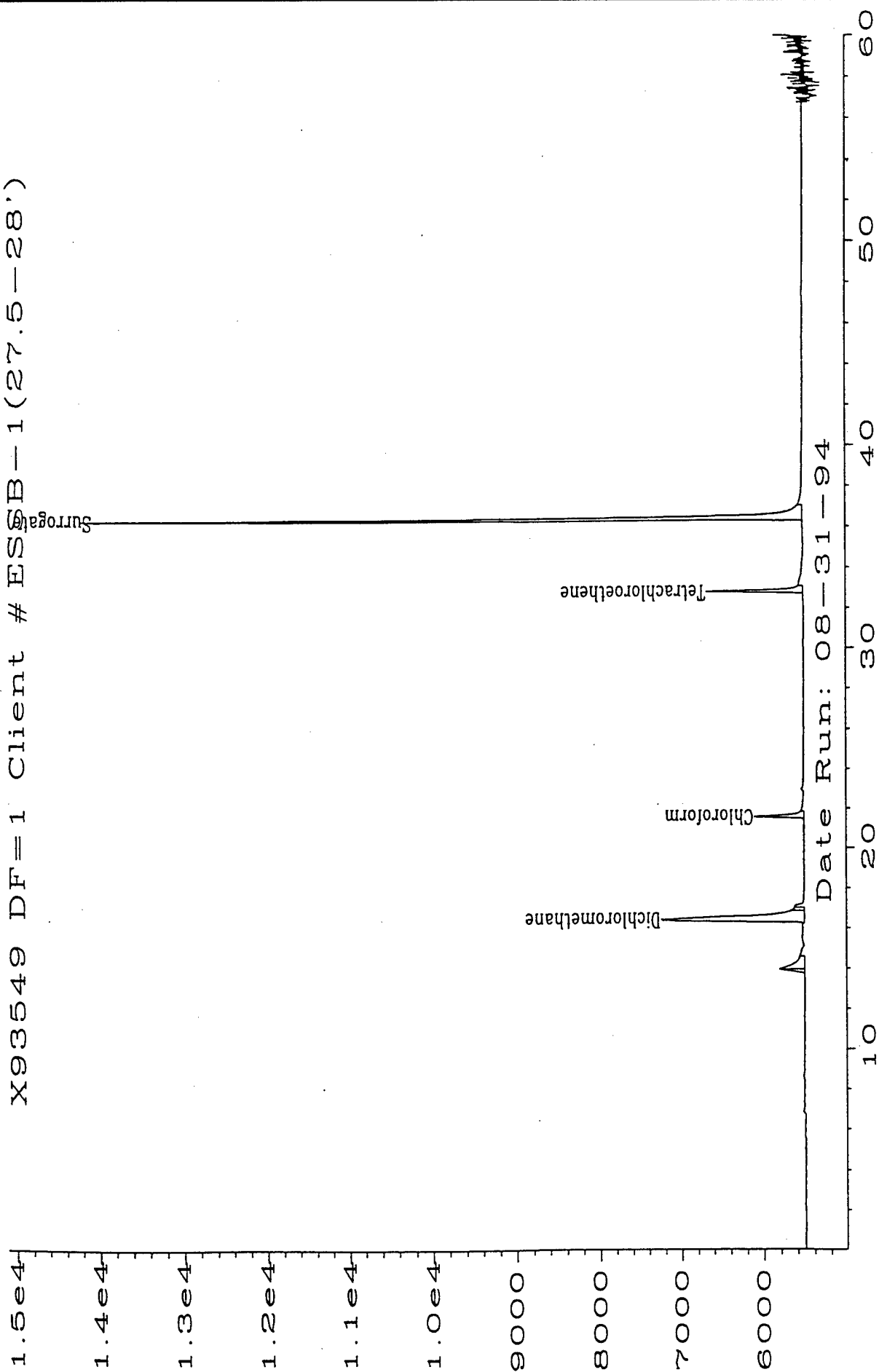
Sig. 2 in C:\HPCHEM\2\DATA\HALL0830\028R0101.D

EVERGREEN ANALYTICAL, INC.
4036 Youngfield, Wheat Ridge, CO 80033
(303) 425-6021

Method 8010 Chlorinated VOC's
Sample Report

Client Sample #	: ESSB-2(2'bgs)	Client Project #	: Battle Creek
Lab Sample #	: X93536	Lab Project #	: 94-3273
Date Sampled	: Not Specified	Matrix	: Soil
Date Received	: 8/29/94	Lab File #	: Hall0830007
Date Prepared	: 8/30/94	Method Blank	: MB083094
Date Analyzed	: 8/30/94	Dilution Factor	: 5.0

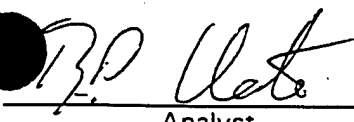| Compound	CAS #	Concentration (ug/Kg)	EDL(ug/Kg)
Dichlorodifluoromethane	75-71-8	U	1
Chloromethane	74-87-3	U	2
Vinyl Chloride	75-01-4	U	1
Bromomethane	74-83-9	U	1
Chloroethane	75-00-3	U	2.5
Trichlorofluoromethane	75-69-4	U	2
1,1-Dichloroethene	75-35-4	U	2
Dichloromethane	75-09-2	14 B	2
trans-1,2-Dichloroethene	156-60-5	U	1
1,1-Dichloroethane	75-34-3	U	1.5
Chloroform	67-66-3	3.6 B	1
1,1,1-Trichloroethane	71-55-6	U	1.5
1,2-Dichloroethane	107-06-2	U	1.5
Carbon Tetrachloride	56-23-5	U	0.5
Trichloroethene	79-01-6	U	1
1,2-Dichloropropane	78-87-5	U	2
Bromodichloromethane	75-27-4	U	0.5
2-Chloroethyl vinyl ether	110-75-8	U	20
cis-1,3-Dichloropropene	10061-01-5	U	2.5
trans-1,3-Dichloropropene	10061-02-6	U	2
1,1,2-Trichloroethane	79-00-5	U	1
Tetrachloroethene	127-18-4	430	1.5
Dibromochloromethane	124-48-1	U	2
Chlorobenzene	108-90-7	U	1
Bromoform	75-25-2	U	1
1,1,2,2-Tetrachloroethane	79-34-5	U	1.5
1,3-Dichlorobenzene	541-73-1	U	2
1,4-Dichlorobenzene	106-46-7	U	2
1,2-Dichlorobenzene	95-50-1	U	2

Surrogate Recovery   (1-Chloro-2-Fluoro-Benzene)   :   71%

QUALIFIERS:
U = Compound analyzed for, but not detected.
B = Compound in blank and sample. Compare blank and sample date.
EDL = Evergreen's Estimated Detection Limit.

_____   _____
Analyst   Approved

X93536 DF=5 Client # ESSB−2(2'bgs)

Surrogate

Tetrachloroethene

Chloroform

Dichloromethane

Date Run: 08−30−94
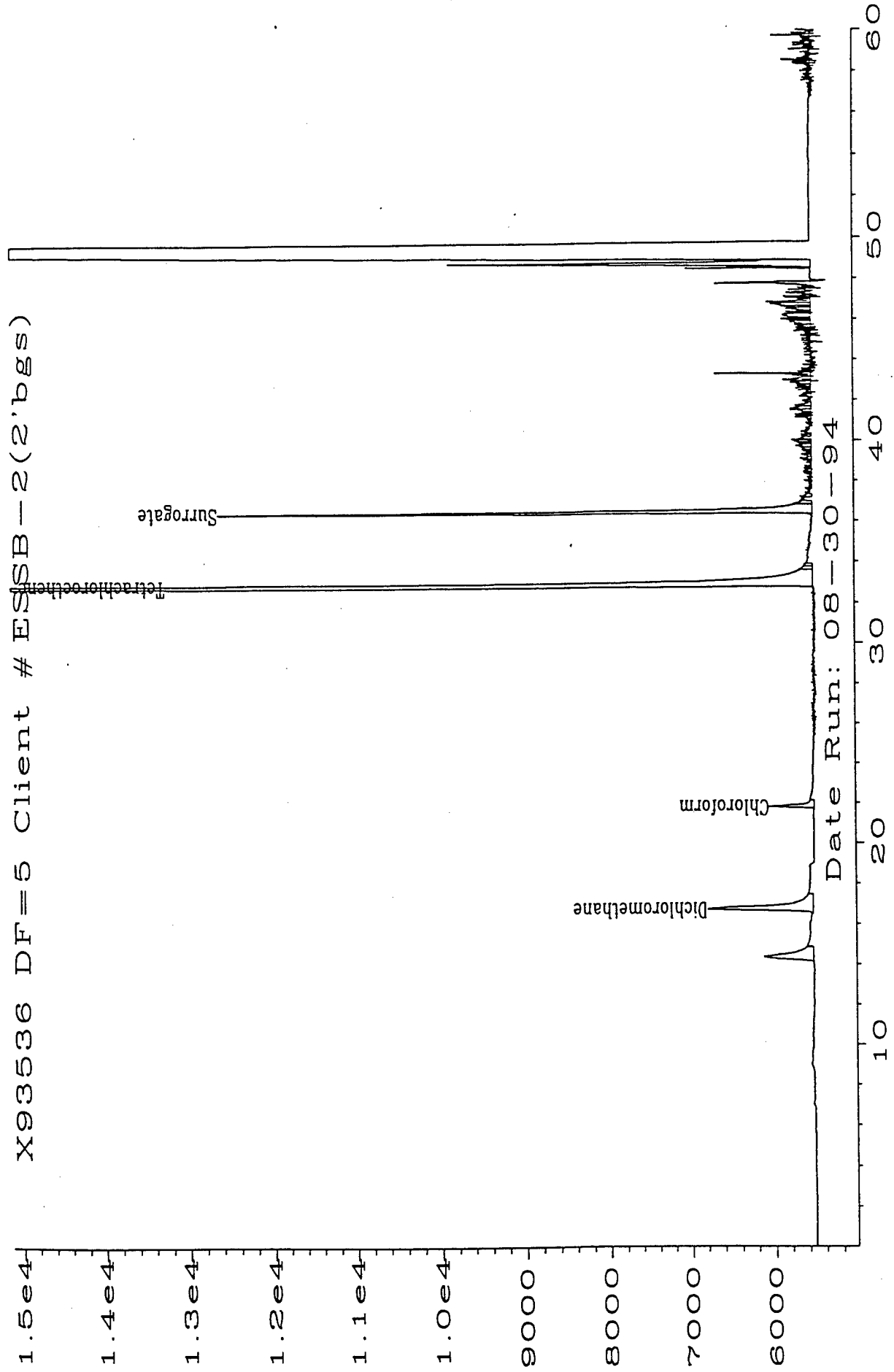
Sig. 2 in C:\HPCHEM\2\DATA\HALL0830\007R0101.D

Method 8010 Chlorinated VOC's
Sample Report

Client Sample #	: ESSB-2(14'bgs)	Client Project #	: Battle Creek
Lab Sample #	: X93537	Lab Project #	: 94-3273
Date Sampled	: Not Specified	Matrix	: Soil
Date Received	: 8/29/94	Lab File #	: Hall0830008
Date Prepared	: 8/30/94	Method Blank	: MB083094
Date Analyzed	: 8/30/94	Dilution Factor	: 5.0

Compound	CAS #	Concentration (ug/Kg)	EDL(ug/Kg)
Dichlorodifluoromethane	75-71-8	U	1
Chloromethane	74-87-3	U	2
Vinyl Chloride	75-01-4	U	1
Bromomethane	74-83-9	U	1
Chloroethane	75-00-3	U	2.5
Trichlorofluoromethane	75-69-4	U	2
1,1-Dichloroethene	75-35-4	U	2
Dichloromethane	75-09-2	11 B	2
trans-1,2-Dichloroethene	156-60-5	U	1
1,1-Dichloroethane	75-34-3	U	1.5
Chloroform	67-66-3	3.5 B	1
1,1,1-Trichloroethane	71-55-6	U	1.5
1,2-Dichloroethane	107-06-2	U	1.5
Carbon Tetrachloride	56-23-5	U	0.5
Trichloroethene	79-01-6	U	1
1,2-Dichloropropane	78-87-5	U	2
Bromodichloromethane	75-27-4	U	0.5
2-Chloroethyl vinyl ether	110-75-8	U	20
cis-1,3-Dichloropropene	10061-01-5	U	2.5
trans-1,3-Dichloropropene	10061-02-6	U	2
1,1,2-Trichloroethane	79-00-5	U	1
Tetrachloroethene	127-18-4	6.9	1.5
Dibromochloromethane	124-48-1	U	2
Chlorobenzene	108-90-7	U	1
Bromoform	75-25-2	U	1
1,1,2,2-Tetrachloroethane	79-34-5	U	1.5
1,3-Dichlorobenzene	541-73-1	U	2
1,4-Dichlorobenzene	106-46-7	U	2
1,2-Dichlorobenzene	95-50-1	U	2

Surrogate Recovery   (1-Chloro-2-Fluoro-Benzene)   :   102%
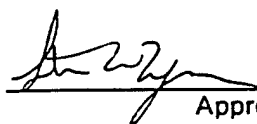
QUALIFIERS:
U = Compound analyzed for, but not detected.
B = Compound in blank and sample. Compare blank and sample date.
EDL = Evergreen's Estimated Detection Limit.

_____
Analyst

_____
Approved

X93537 DF=5 Client # ESSB-2(14'bgs)

Surrogate

Tetrachloroethene

Chloroform

Dichloromethane

Date Run: 08-30-94
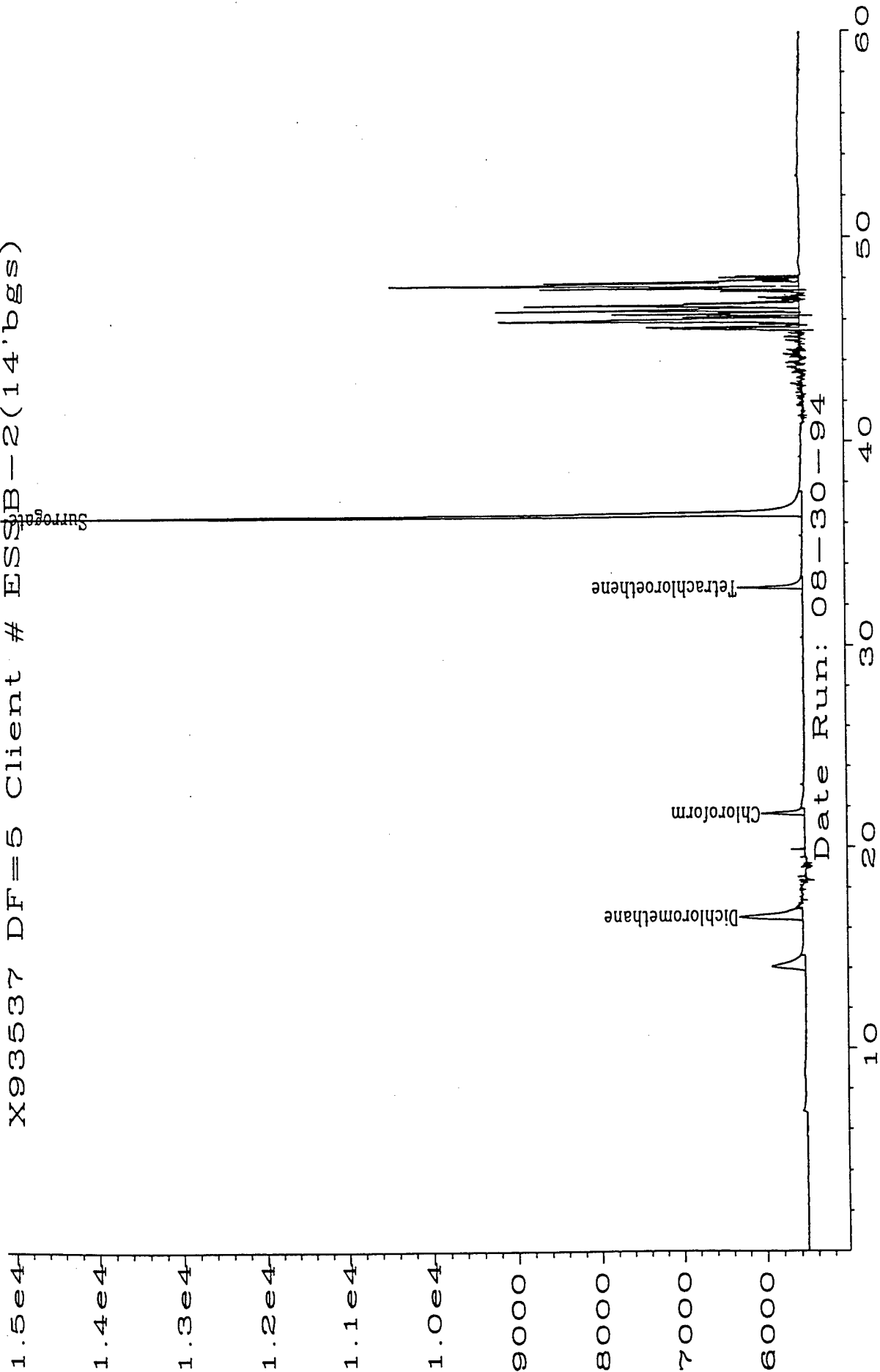
Sig. 2 in C:\HPCHEM\2\DATA\HALLO830\008R0101.D

Method 8010 Chlorinated VOC's
Sample Report

Client Sample #	: ESSB-2(21.75bgs)	Client Project #	: Battle Creek
Lab Sample #	: X93539	Lab Project #	: 94-3273
Date Sampled	: Not Specified	Matrix	: Soil
Date Received	: 8/29/94	Lab File #	: Hall0830010
Date Prepared	: 8/30/94	Method Blank	: MB083094
Date Analyzed	: 8/30/94	Dilution Factor	: 1.0

Compound	CAS #	Concentration (ug/Kg)	EDL(ug/Kg)
Dichlorodifluoromethane	75-71-8	U	0.2
Chloromethane	74-87-3	U	0.4
Vinyl Chloride	75-01-4	U	0.2
Bromomethane	74-83-9	U	0.2
Chloroethane	75-00-3	U	0.5
Trichlorofluoromethane	75-69-4	U	0.4
1,1-Dichloroethene	75-35-4	U	0.4
Dichloromethane	75-09-2	2.0 B	0.4
trans-1,2-Dichloroethene	156-60-5	U	0.2
1,1-Dichloroethane	75-34-3	U	0.3
Chloroform	67-66-3	0.5 B	0.2
1,1,1-Trichloroethane	71-55-6	U	0.3
1,2-Dichloroethane	107-06-2	U	0.3
Carbon Tetrachloride	56-23-5	U	0.1
Trichloroethene	79-01-6	U	0.2
1,2-Dichloropropane	78-87-5	U	0.4
Bromodichloromethane	75-27-4	U	0.1
2-Chloroethyl vinyl ether	110-75-8	U	4.0
cis-1,3-Dichloropropene	10061-01-5	U	0.5
trans-1,3-Dichloropropene	10061-02-6	U	0.4
1,1,2-Trichloroethane	79-00-5	U	0.2
Tetrachloroethene	127-18-4	1.5	0.3
Dibromochloromethane	124-48-1	U	0.4
Chlorobenzene	108-90-7	U	0.2
Bromoform	75-25-2	U	0.2
1,1,2,2-Tetrachloroethane	79-34-5	U	0.3
1,3-Dichlorobenzene	541-73-1	U	0.4
1,4-Dichlorobenzene	106-46-7	U	0.4
1,2-Dichlorobenzene	95-50-1	U	0.4

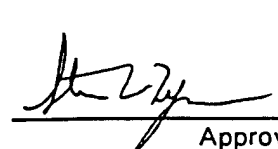Surrogate Recovery   (1-Chloro-2-Fluoro-Benzene)   :   74%

QUALIFIERS:
U = Compound analyzed for, but not detected.
B = Compound in blank and sample. Compare blank and sample date.
EDL = Evergreen's Estimated Detection Limit.

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Analyst

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Approved

X93539 DF=1 Client # ESSB-2(21.75'bgs)
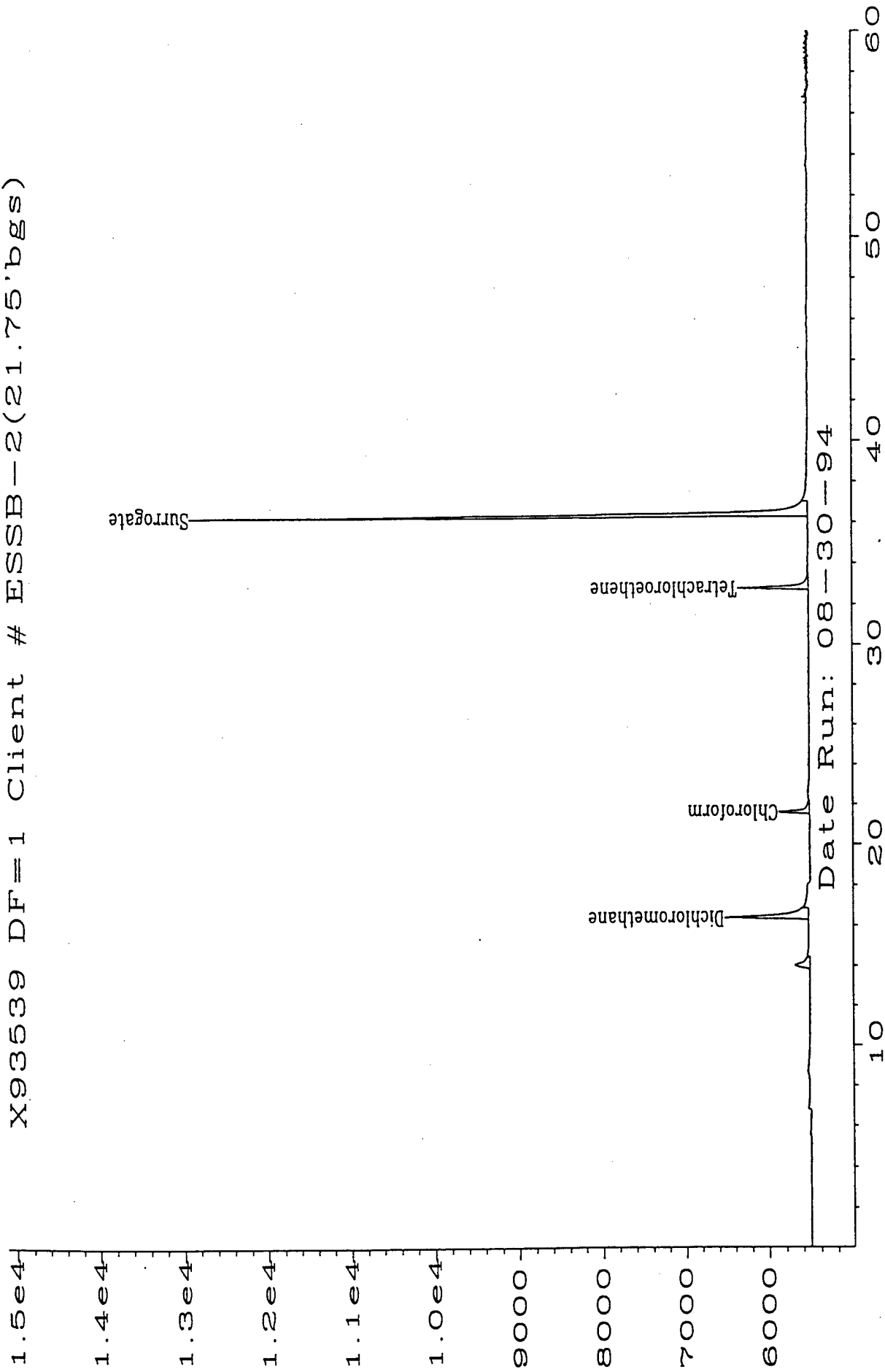
Sig. 2 in C:\HPCHEM\2\DATA\HALLO830\010R0101.D

EVERGREEN ANALYTICAL, INC.
4036 Youngfield, Wheat Ridge, CO 80033
(303) 425-6021

Method 8010 Chlorinated VOC's
Sample Report

Client Sample #	: ESSB-3(2-2.5')	Client Project #	: Battle Creek
Lab Sample #	: X93546	Lab Project #	: 94-3273
Date Sampled	: Not Specified	Matrix	: Soil
Date Received	: 8/29/94	Lab File #	: Hall0830017
Date Prepared	: 8/30/94	Method Blank	: MB083094
Date Analyzed	: 8/31/94	Dilution Factor	: 5.0

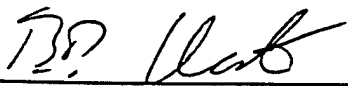| Compound	CAS #	Concentration (ug/Kg)	EDL(ug/Kg)
Dichlorodifluoromethane	75-71-8	U	1
Chloromethane	74-87-3	U	2
Vinyl Chloride	75-01-4	U	1
Bromomethane	74-83-9	U	1
Chloroethane	75-00-3	U	2.5
Trichlorofluoromethane	75-69-4	U	2
1,1-Dichloroethene	75-35-4	U	2
Dichloromethane	75-09-2	12 B	2
trans-1,2-Dichloroethene	156-60-5	U	1
1,1-Dichloroethane	75-34-3	U	1.5
Chloroform	67-66-3	3.1 B	1
1,1,1-Trichloroethane	71-55-6	1.5	1.5
1,2-Dichloroethane	107-06-2	U	1.5
Carbon Tetrachloride	56-23-5	U	0.5
Trichloroethene	79-01-6	U	1
1,2-Dichloropropane	78-87-5	U	2
Bromodichloromethane	75-27-4	U	0.5
2-Chloroethyl vinyl ether	110-75-8	U	20
cis-1,3-Dichloropropene	10061-01-5	U	2.5
trans-1,3-Dichloropropene	10061-02-6	U	2
1,1,2-Trichloroethane	79-00-5	U	1
Tetrachloroethene	127-18-4	3.0	1.5
Dibromochloromethane	124-48-1	U	2
Chlorobenzene	108-90-7	U	1
Bromoform	75-25-2	U	1
1,1,2,2-Tetrachloroethane	79-34-5	U	1.5
1,3-Dichlorobenzene	541-73-1	U	2
1,4-Dichlorobenzene	106-46-7	U	2
1,2-Dichlorobenzene	95-50-1	U	2

Surrogate Recovery   (1-Chloro-2-Fluoro-Benzene)   :   88%

QUALIFIERS:
U = Compound analyzed for, but not detected.
B = Compound in blank and sample. Compare blank and sample date.
EDL = Evergreen's Estimated Detection Limit.

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X93546 DF=5 Client # ESSB-3(2-2.5')
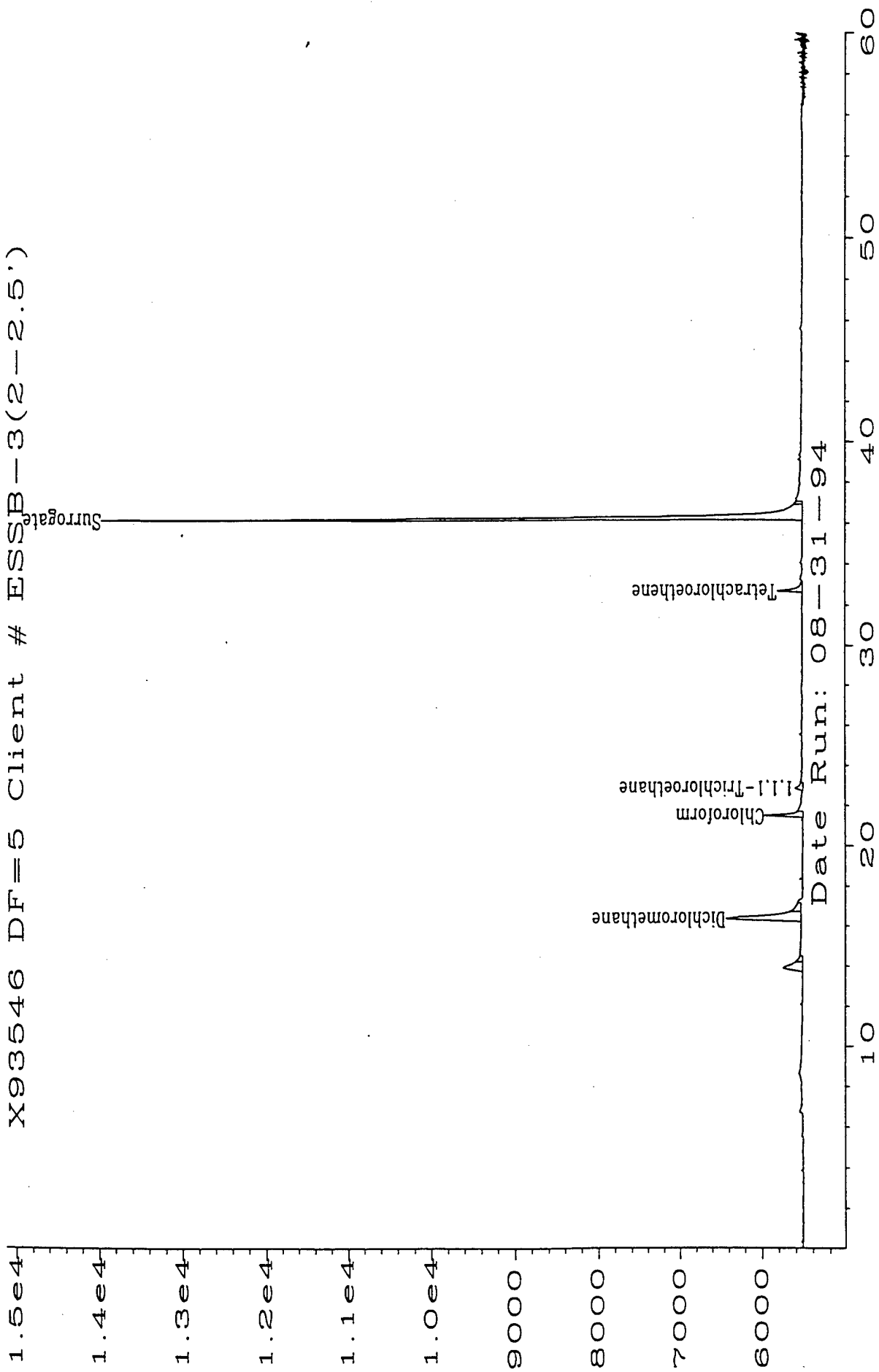
Sig. 2 in C:\HPCHEM\2\DATA\HALLO830\017R0101.D

EVERGREEN ANALYTICAL, INC.
4036 Youngfield, Wheat Ridge, CO 80033
(303) 425-6021

Method 8010 Chlorinated VOC's
Sample Report

Client Sample #	: ESSB-3(14'-14.5bgs)	Client Project #	: Battle Creek
Lab Sample #	: X93540	Lab Project #	: 94-3273
Date Sampled	: Not Specified	Matrix	: Soil
Date Received	: 8/29/94	Lab File #	: Hall0830011
Date Prepared	: 8/30/94	Method Blank	: MB083094
Date Analyzed	: 8/30/94	Dilution Factor	: 1.0

Compound	CAS #	Concentration (ug/Kg)	EDL(ug/Kg)
Dichlorodifluoromethane	75-71-8	U	0.2
Chloromethane	74-87-3	U	0.4
Vinyl Chloride	75-01-4	U	0.2
Bromomethane	74-83-9	U	0.2
Chloroethane	75-00-3	U	0.5
Trichlorofluoromethane	75-69-4	U	0.4
1,1-Dichloroethene	75-35-4	U	0.4
Dichloromethane	75-09-2	3.0 B	0.4
trans-1,2-Dichloroethene	156-60-5	U	0.2
1,1-Dichloroethane	75-34-3	U	0.3
Chloroform	67-66-3	0.8 B	0.2
1,1,1-Trichloroethane	71-55-6	U	0.3
1,2-Dichloroethane	107-06-2	U	0.3
Carbon Tetrachloride	56-23-5	U	0.1
Trichloroethene	79-01-6	U	0.2
1,2-Dichloropropane	78-87-5	U	0.4
Bromodichloromethane	75-27-4	U	0.1
2-Chloroethyl vinyl ether	110-75-8	U	4.0
cis-1,3-Dichloropropene	10061-01-5	U	0.5
trans-1,3-Dichloropropene	10061-02-6	U	0.4
1,1,2-Trichloroethane	79-00-5	U	0.2
Tetrachloroethene	127-18-4	2.8	0.3
Dibromochloromethane	124-48-1	U	0.4
Chlorobenzene	108-90-7	U	0.2
Bromoform	75-25-2	U	0.2
1,1,2,2-Tetrachloroethane	79-34-5	U	0.3
1,3-Dichlorobenzene	541-73-1	U	0.4
1,4-Dichlorobenzene	106-46-7	U	0.4
1,2-Dichlorobenzene	95-50-1	U	0.4

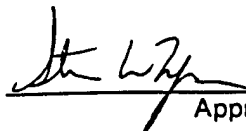Surrogate Recovery   (1-Chloro-2-Fluoro-Benzene)   :   94%

QUALIFIERS:
U = Compound analyzed for, but not detected.
B = Compound in blank and sample. Compare blank and sample date.
EDL = Evergreen's Estimated Detection Limit.

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Analyst

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Approved

X93540 DF=1 Client # ESSB-3(14'-14.5bgs)
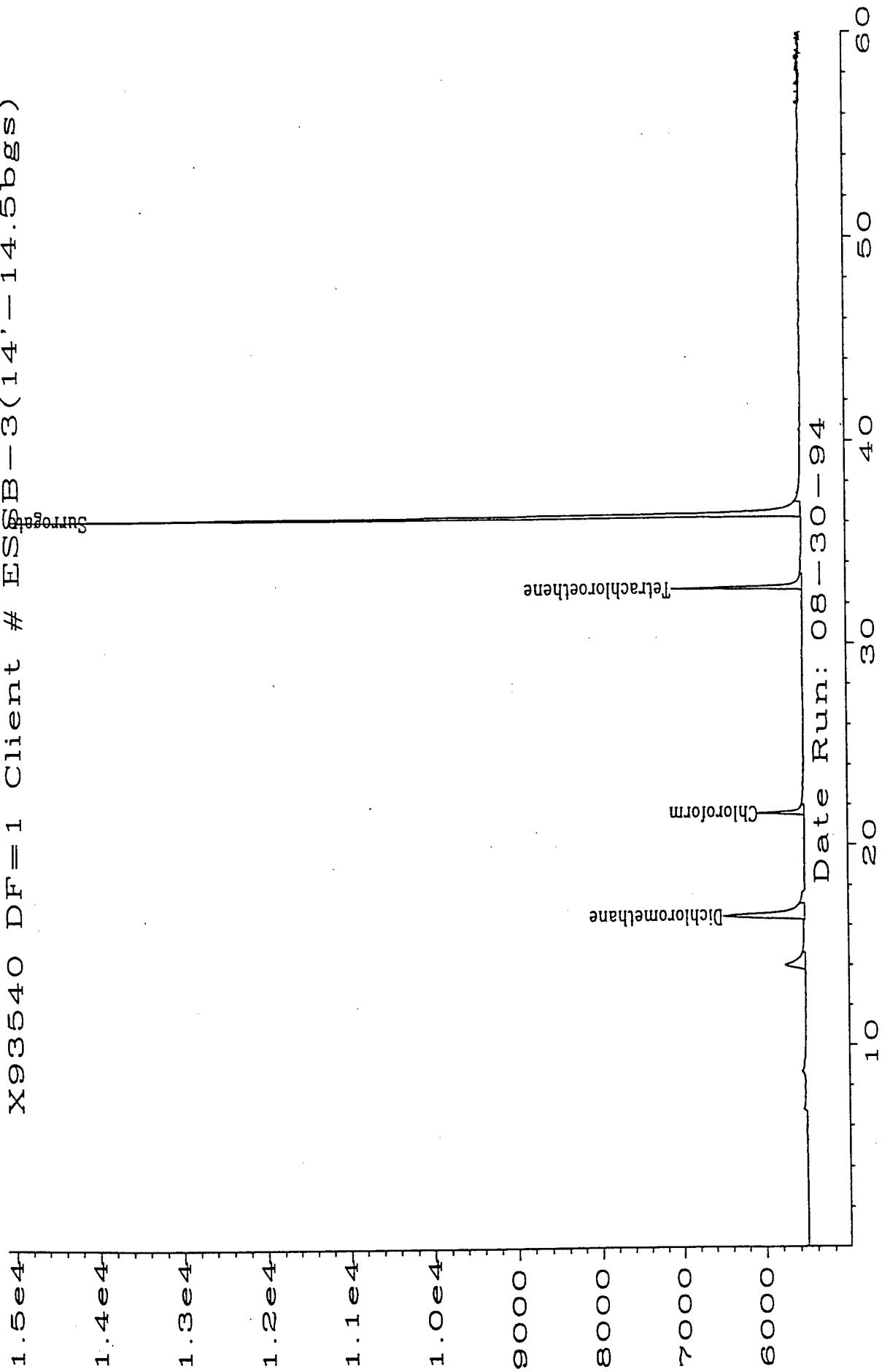
Date Run: 08-30-94

Sig. 2 in C:\HPCHEM\2\DATA\HALLO830\011R0101.D

Method 8010 Chlorinated VOC's
Sample Report

Client Sample #	: ESSB-3(22-22.5')	Client Project #	: Battle Creek
Lab Sample #	: X93552	Lab Project #	: 94-3273
Date Sampled	: Not Specified	Matrix	: Soil
Date Received	: 8/29/94	Lab File #	: Hall0830031
Date Prepared	: 8/31/94	Method Blank	: MB083194
Date Analyzed	: 8/31/94	Dilution Factor	: 1.0

Compound	CAS #	Concentration (ug/Kg)	EDL(ug/Kg)
Dichlorodifluoromethane	75-71-8	U	0.2
Chloromethane	74-87-3	U	0.4
Vinyl Chloride	75-01-4	U	0.2
Bromomethane	74-83-9	U	0.2
Chloroethane	75-00-3	U	0.3
Trichlorofluoromethane	75-69-4	U	0.4
1,1-Dichloroethene	75-35-4	U	0.4
Dichloromethane	75-09-2	2.3 B	0.4
trans-1,2-Dichloroethene	156-60-5	U	0.2
1,1-Dichloroethane	75-34-3	U	0.3
Chloroform	67-66-3	0.8 B	0.2
1,1,1-Trichloroethane	71-55-6	U	0.3
1,2-Dichloroethane	107-06-2	U	0.3
Carbon Tetrachloride	56-23-5	U	0.1
Trichloroethene	79-01-6	U	0.2
1,2-Dichloropropane	78-87-5	U	0.4
Bromodichloromethane	75-27-4	U	0.1
2-Chloroethyl vinyl ether	110-75-8	U	4.0
cis-1,3-Dichloropropene	10061-01-5	U	0.5
trans-1,3-Dichloropropene	10061-02-6	U	0.4
1,1,2-Trichloroethane	79-00-5	U	0.2
Tetrachloroethene	127-18-4	2.6	0.3
Dibromochloromethane	124-48-1	U	0.4
Chlorobenzene	108-90-7	U	0.2
Bromoform	75-25-2	U	0.2
1,1,2,2-Tetrachloroethane	79-34-5	U	0.3
1,3-Dichlorobenzene	541-73-1	U	0.4
1,4-Dichlorobenzene	106-46-7	U	0.4
1,2-Dichlorobenzene	95-50-1	U	0.4

Surrogate Recovery   (1-Chloro-2-Fluoro-Benzene)   :   83%

QUALIFIERS:
U = Compound analyzed for, but not detected.
B = Compound in blank and sample. Compare blank and sample date.
EDL = Evergreen's Estimated Detection Limit.

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Analyst

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Approved

X93552 DF=1 Client # ESSB-3(22-22.5')

Surrogate
Tetrachloroethene
Chloroform
Dichloromethane

Date Run: 08-31-94
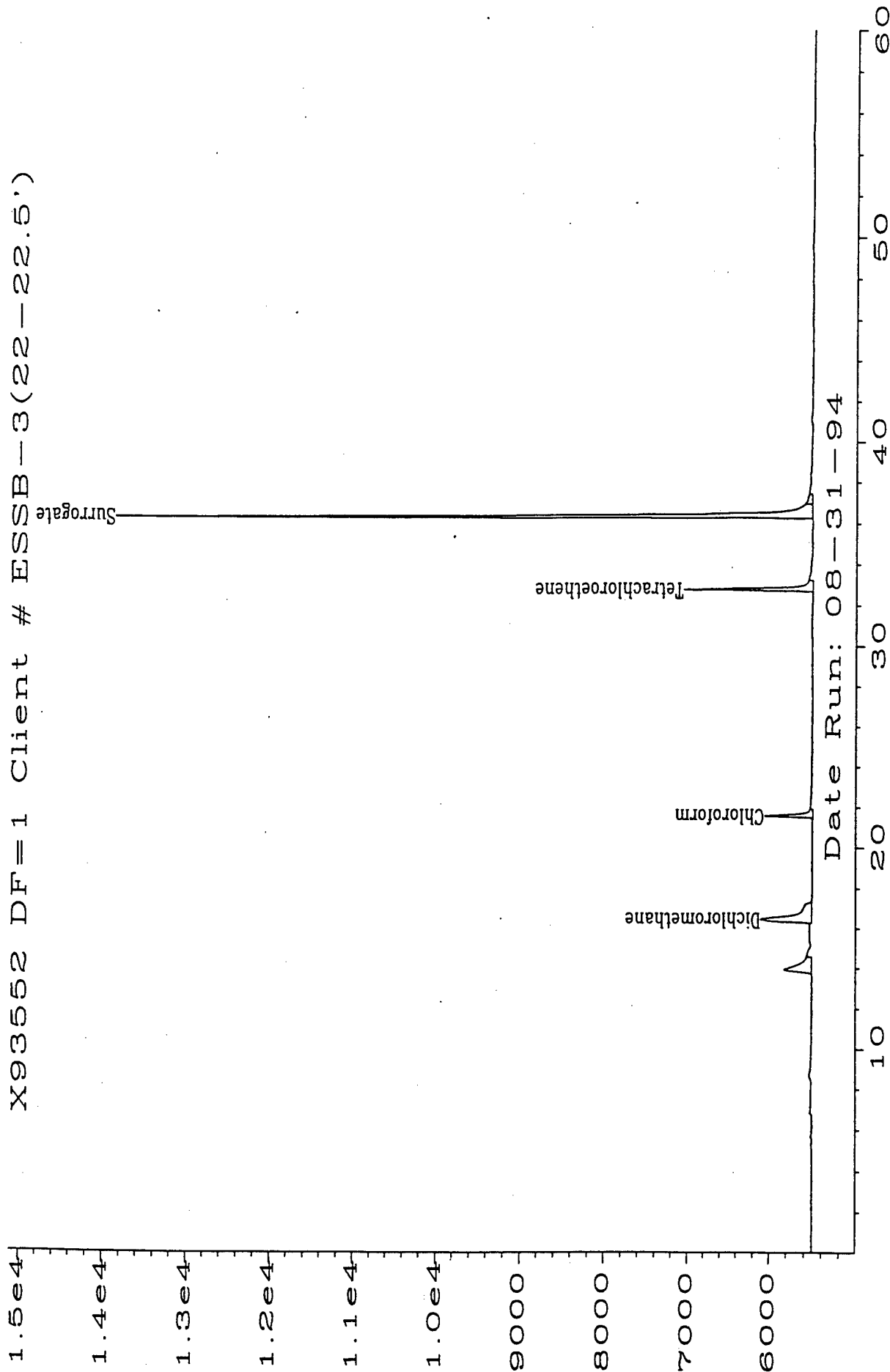
Sig. 2 in C:\HPCHEM\2\DATA\HALLO830\031R0101.D

EVERGREEN ANALYTICAL, INC.
4036 Youngfield, Wheat Ridge, CO 80033
(303) 425-6021

Method 8010 Chlorinated VOC's
Sample Report

Client Sample #	: ESSB-4(2'bgs)	Client Project #	: Battle Creek
Lab Sample #	: X93543	Lab Project #	: 94-3273
Date Sampled	: Not Specified	Matrix	: Soil
Date Received	: 8/29/94	Lab File #	: Hall0830014
Date Prepared	: 8/30/94	Method Blank	: MB083094
Date Analyzed	: 8/31/94	Dilution Factor	: 5.0

Compound	CAS #	Concentration (ug/Kg)	EDL(ug/Kg)
Dichlorodifluoromethane	75-71-8	U	1
Chloromethane	74-87-3	U	2
Vinyl Chloride	75-01-4	U	1
Bromomethane	74-83-9	U	1
Chloroethane	75-00-3	U	2.5
Trichlorofluoromethane	75-69-4	U	2
1,1-Dichloroethene	75-35-4	U	2
Dichloromethane	75-09-2	25 B	2
trans-1,2-Dichloroethene	156-60-5	U	1
1,1-Dichloroethane	75-34-3	U	1.5
Chloroform	67-66-3	3.4 B	1
1,1,1-Trichloroethane	71-55-6	U	1.5
1,2-Dichloroethane	107-06-2	U	1.5
Carbon Tetrachloride	56-23-5	U	0.5
Trichloroethene	79-01-6	U	1
1,2-Dichloropropane	78-87-5	U	2
Bromodichloromethane	75-27-4	U	0.5
2-Chloroethyl vinyl ether	110-75-8	U	20
cis-1,3-Dichloropropene	10061-01-5	U	2.5
trans-1,3-Dichloropropene	10061-02-6	U	2
1,1,2-Trichloroethane	79-00-5	U	1
Tetrachloroethene	127-18-4	22000 (Extrapolated)	1.5
Dibromochloromethane	124-48-1	U	2
Chlorobenzene	108-90-7	U	1
Bromoform	75-25-2	U	1
1,1,2,2-Tetrachloroethane	79-34-5	U	1.5
1,3-Dichlorobenzene	541-73-1	U	2
1,4-Dichlorobenzene	106-46-7	U	2
1,2-Dichlorobenzene	95-50-1	U	2

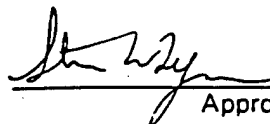Surrogate Recovery   (1-Chloro-2-Fluoro-Benzene)   :   89%

QUALIFIERS:
U = Compound analyzed for, but not detected.
B = Compound in blank and sample. Compare blank and sample date.
EDL = Evergreen's Estimated Detection Limit.

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Analyst

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Approved

X93543 DF=5 Client # EPSB-4(2'bgs)

Surrogate

Tetrachloroethane

Chloroform

Dichloromethane

Date Run: 08-31-94

1.5e4
1.4e4
1.3e4
1.2e4
1.1e4
1.0e4
9000
8000
7000
6000

10   20   30   40   50   60

Sig. 2 in C:\HPCHEM\2\DATA\HALL0830\014R0101.D

EVERGREEN ANALYTICAL, INC.
4036 Youngfield, Wheat Ridge, CO 80033
(303) 425-6021

Method 8010 Chlorinated VOC's
Sample Report

Client Sample #	: ESSB-4(2'bgs)	Client Project #	: Battle Creek
Lab Sample #	: X93543	Lab Project #	: 94-3273
Date Sampled	: Not Specified	Matrix	: Soil
Date Received	: 8/29/94	Lab File #	: Hall0908007
Date Prepared	: 9/8/94	Method Blank	: MEB090894
Date Analyzed	: 9/8/94	Dilution Factor	: 125.0

Compound	CAS #	Concentration (ug/Kg)	EDL(ug/Kg)
Dichlorodifluoromethane	75-71-8	U	25
Chloromethane	74-87-3	U	50
Vinyl Chloride	75-01-4	U	25
Bromomethane	74-83-9	U	25
Chloroethane	75-00-3	U	63
Trichlorofluoromethane	75-69-4	U	50
1,1-Dichloroethene	75-35-4	U	50
Dichloromethane	75-09-2	210 B	50
trans-1,2-Dichloroethene	156-60-5	U	25
1,1-Dichloroethane	75-34-3	U	38
Chloroform	67-66-3	140 B	25
1,1,1-Trichloroethane	71-55-6	U	38
1,2-Dichloroethane	107-06-2	U	38
Carbon Tetrachloride	56-23-5	U	13
Trichloroethene	79-01-6	U	25
1,2-Dichloropropane	78-87-5	U	50
Bromodichloromethane	75-27-4	U	13
2-Chloroethyl vinyl ether	110-75-8	U	500
cis-1,3-Dichloropropene	10061-01-5	U	63
trans-1,3-Dichloropropene	10061-02-6	U	50
1,1,2-Trichloroethane	79-00-5	U	25
Tetrachloroethene	127-18-4	7800	38
Dibromochloromethane	124-48-1	U	50
Chlorobenzene	108-90-7	U	25
Bromoform	75-25-2	U	25
1,1,2,2-Tetrachloroethane	79-34-5	U	38
1,3-Dichlorobenzene	541-73-1	U	50
1,4-Dichlorobenzene	106-46-7	U	50
1,2-Dichlorobenzene	95-50-1	U	50

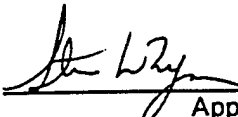Surrogate Recovery   (1-Chloro-2-Fluoro-Benzene)   :   120%

QUALIFIERS:
U = Compound analyzed for, but not detected.
B = Compound in blank and sample. Compare blank and sample date.
EDL = Evergreen's Estimated Detection Limit.

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Analyst

_____
Approved

X93543 DF=125 Client #ESSB-4(2'bgs)

Surrogate

Tetrachloroethene

Chloroform

Dichloromethane

1.5e4
1.4e4
1.3e4
1.2e4
1.1e4
1.0e4
9000
8000
7000
6000

10   20   30   40   50   60

Date Run: 09-08-94

Sig. 2 in C:\HPCHEM\2\DATA\HALLO908\007RO101.D

Method 8010 Chlorinated VOC's
Sample Report

Client Sample #	: ESSB-4(14'bgs)	Client Project #	: Battle Creek
Lab Sample #	: X93541	Lab Project #	: 94-3273
Date Sampled	: Not Specified	Matrix	: Soil
Date Received	: 8/29/94	Lab File #	: Hall0830012
Date Prepared	: 8/30/94	Method Blank	: MB083094
Date Analyzed	: 8/30/94	Dilution Factor	: 5.0

Compound	CAS #	Concentration (ug/Kg)	EDL(ug/Kg)
Dichlorodifluoromethane	75-71-8	U	1
Chloromethane	74-87-3	U	2
Vinyl Chloride	75-01-4	U	1
Bromomethane	74-83-9	U	1
Chloroethane	75-00-3	U	2.5
Trichlorofluoromethane	75-69-4	U	2
1,1-Dichloroethene	75-35-4	U	2
Dichloromethane	75-09-2	12 B	2
trans-1,2-Dichloroethene	156-60-5	U	1
1,1-Dichloroethane	75-34-3	U	1.5
Chloroform	67-66-3	3.7 B	1
1,1,1-Trichloroethane	71-55-6	U	1.5
1,2-Dichloroethane	107-06-2	U	1.5
Carbon Tetrachloride	56-23-5	U	0.5
Trichloroethene	79-01-6	U	1
1,2-Dichloropropane	78-87-5	U	2
Bromodichloromethane	75-27-4	U	0.5
2-Chloroethyl vinyl ether	110-75-8	U	20
cis-1,3-Dichloropropene	10061-01-5	U	2.5
trans-1,3-Dichloropropene	10061-02-6	U	2
1,1,2-Trichloroethane	79-00-5	U	1
Tetrachloroethene	127-18-4	350	1.5
Dibromochloromethane	124-48-1	U	2
Chlorobenzene	108-90-7	U	1
Bromoform	75-25-2	U	1
1,1,2,2-Tetrachloroethane	79-34-5	U	1.5
1,3-Dichlorobenzene	541-73-1	U	2
1,4-Dichlorobenzene	106-46-7	U	2
1,2-Dichlorobenzene	95-50-1	U	2

Surrogate Recovery   (1-Chloro-2-Fluoro-Benzene)   :   92%
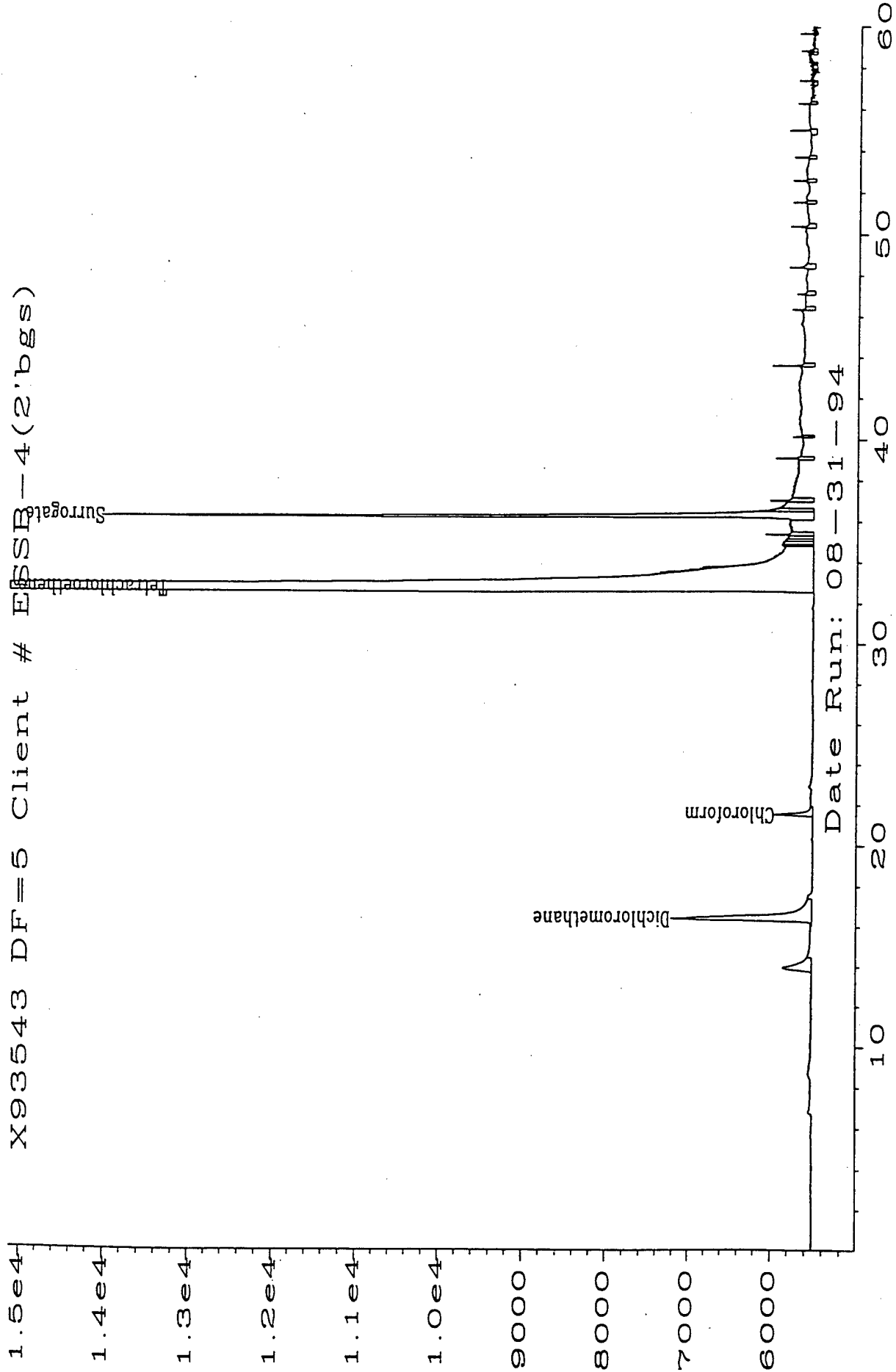
QUALIFIERS:
U = Compound analyzed for, but not detected.
B = Compound in blank and sample. Compare blank and sample date.
EDL = Evergreen's Estimated Detection Limit.

_____ Analyst	_____ Approved

X93541 DF=5 Client # ESSB-4(14'bgs)

Surrogate

Tetrachloroethene

Chloroform

Dichloromethane

Date Run: 08-30-94

Sig. 2 in C:\HPCHEM\2\DATA\HALLO830\012R0101.D

Method 8010 Chlorinated VOC's
Sample Report

Client Sample #	: ESSB-4(21.5'bgs)	Client Project #	: Battle Creek
Lab Sample #	: X93542	Lab Project #	: 94-3273
Date Sampled	: Not Specified	Matrix	: Soil
Date Received	: 8/29/94	Lab File #	: Hall0830013
Date Prepared	: 8/30/94	Method Blank	: MB083094
Date Analyzed	: 8/30/94	Dilution Factor	: 5.0

Compound	CAS #	Concentration (ug/Kg)	EDL(ug/Kg)
Dichlorodifluoromethane	75-71-8	U	1
Chloromethane	74-87-3	U	2
Vinyl Chloride	75-01-4	U	1
Bromomethane	74-83-9	U	1
Chloroethane	75-00-3	U	2.5
Trichlorofluoromethane	75-69-4	U	2
1,1-Dichloroethene	75-35-4	U	2
Dichloromethane	75-09-2	16 B	2
trans-1,2-Dichloroethene	156-60-5	U	1
1,1-Dichloroethane	75-34-3	U	1.5
Chloroform	67-66-3	4.2 B	1
1,1,1-Trichloroethane	71-55-6	U	1.5
1,2-Dichloroethane	107-06-2	U	1.5
Carbon Tetrachloride	56-23-5	U	0.5
Trichloroethene	79-01-6	U	1
1,2-Dichloropropane	78-87-5	U	2
Bromodichloromethane	75-27-4	U	0.5
2-Chloroethyl vinyl ether	110-75-8	U	20
cis-1,3-Dichloropropene	10061-01-5	U	2.5
trans-1,3-Dichloropropene	10061-02-6	U	2
1,1,2-Trichloroethane	79-00-5	U	1
Tetrachloroethene	127-18-4	1000 (Extrapolated)	1.5
Dibromochloromethane	124-48-1	U	2
Chlorobenzene	108-90-7	U	1
Bromoform	75-25-2	U	1
1,1,2,2-Tetrachloroethane	79-34-5	U	1.5
1,3-Dichlorobenzene	541-73-1	U	2
1,4-Dichlorobenzene	106-46-7	U	2
1,2-Dichlorobenzene	95-50-1	U	2

Surrogate Recovery   (1-Chloro-2-Fluoro-Benzene)   :   102%

QUALIFIERS:
U = Compound analyzed for, but not detected.
B = Compound in blank and sample. Compare blank and sample date.
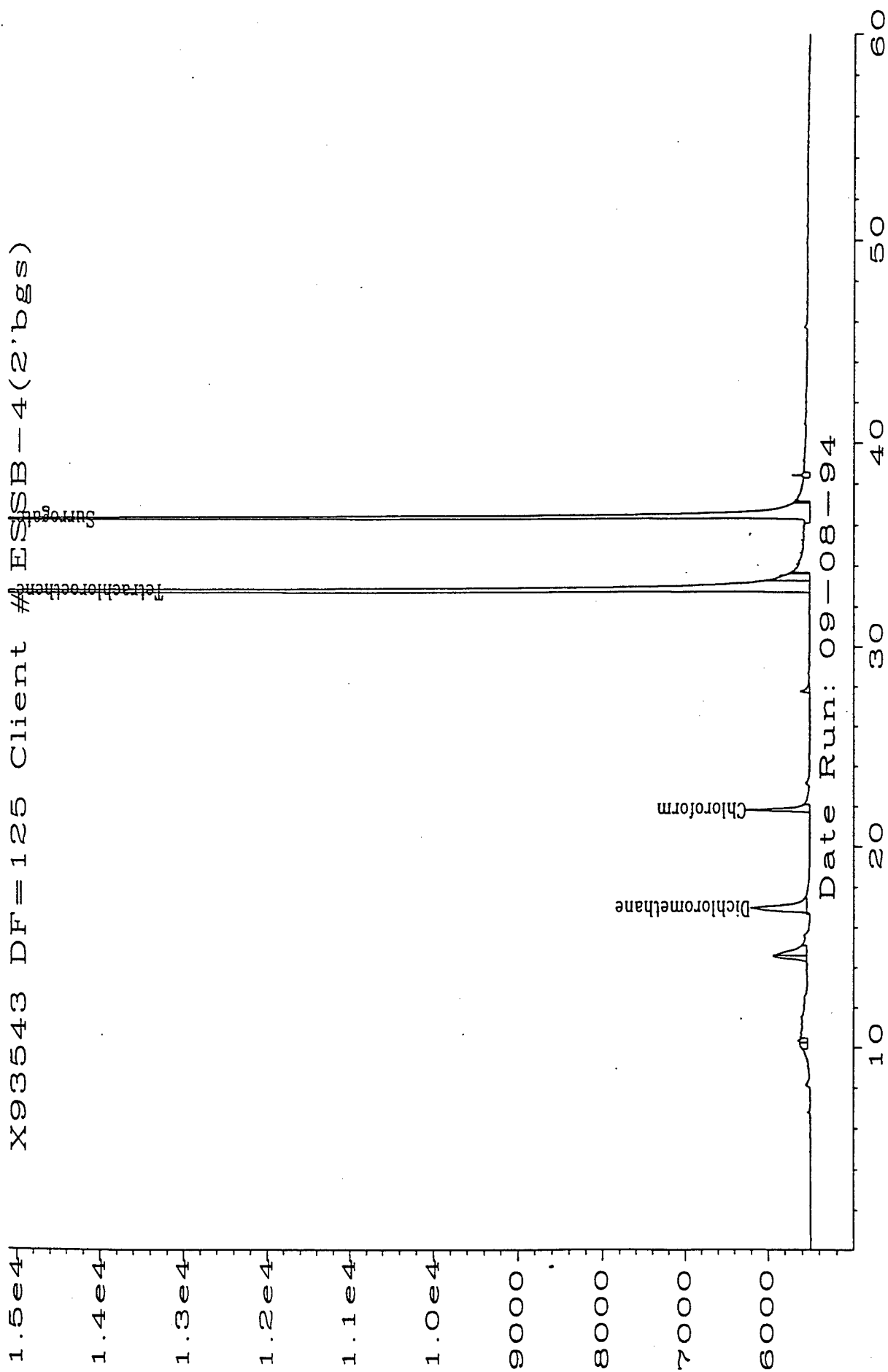EDL = Evergreen's Estimated Detection Limit.

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Analyst

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Approved

X93542 DF=5 Client #ESB-4(21.5'bgs)
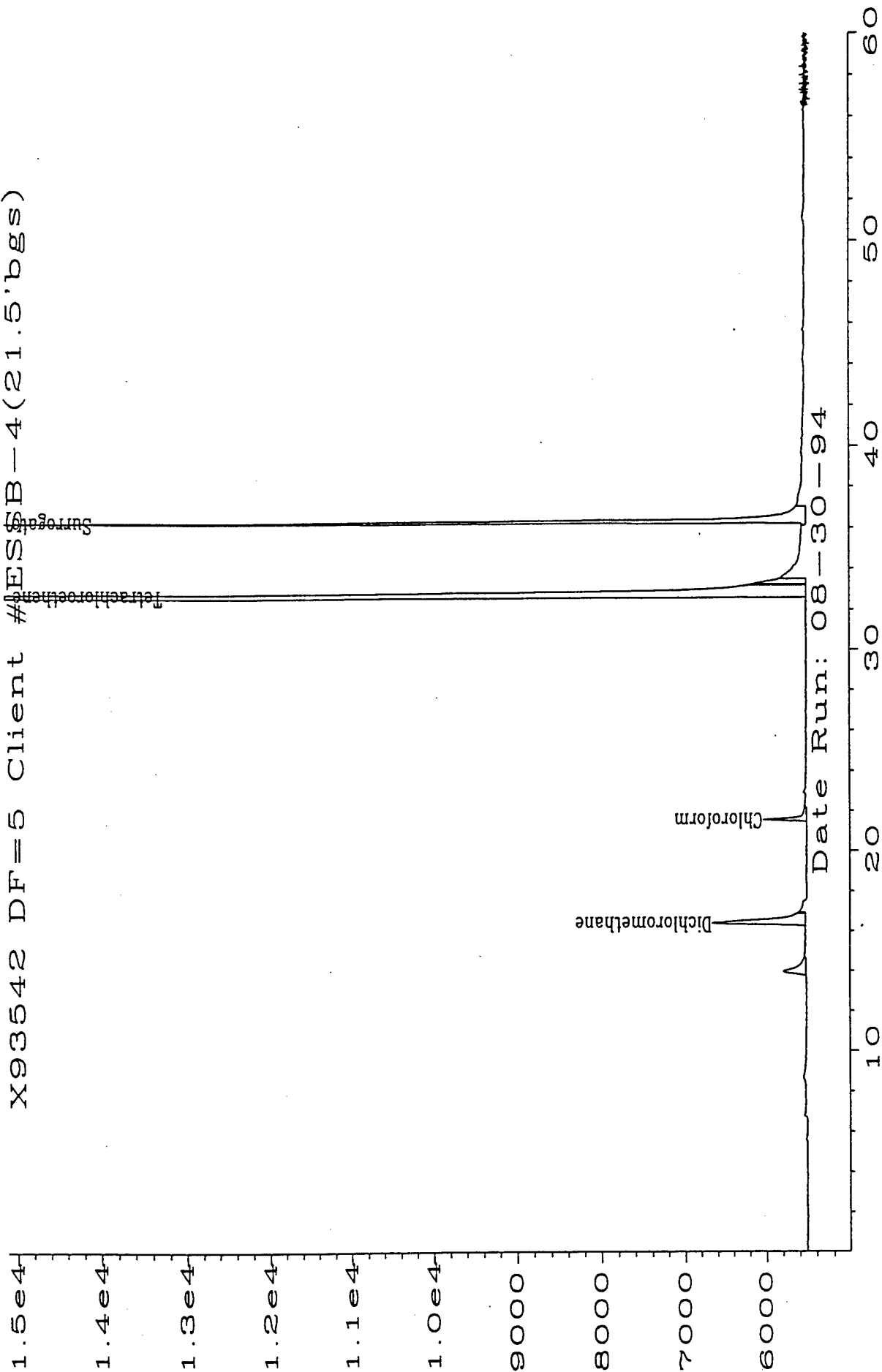
Date Run: 08-30-94

Sig. 2 in C:\HPCHEM\2\DATA\HALLO830\O13RO101.D

EVERGREEN ANALYTICAL, INC.
4036 Youngfield, Wheat Ridge, CO 80033
(303) 425-6021

Method 8010 Chlorinated VOC's
Sample Report

Client Sample #	: ESSB-4(21.5'bgs)	Client Project #	: Battle Creek
Lab Sample #	: X93542	Lab Project #	: 94-3273
Date Sampled	: Not Specified	Matrix	: Soil
Date Received	: 8/29/94	Lab File #	: Hall0908006
Date Prepared	: 9/8/94	Method Blank	: MEB090894
Date Analyzed	: 9/8/94	Dilution Factor	: 125.0

Compound	CAS #	Concentration (ug/Kg)	EDL(ug/Kg)
Dichlorodifluoromethane	75-71-8	U	25
Chloromethane	74-87-3	U	50
Vinyl Chloride	75-01-4	U	25
Bromomethane	74-83-9	U	25
Chloroethane	75-00-3	U	63
Trichlorofluoromethane	75-69-4	U	50
1,1-Dichloroethene	75-35-4	U	50
Dichloromethane	75-09-2	140 B	50
trans-1,2-Dichloroethene	156-60-5	U	25
1,1-Dichloroethane	75-34-3	U	38
Chloroform	67-66-3	120 B	25
1,1,1-Trichloroethane	71-55-6	U	38
Dichloroethane	107-06-2	U	38
bon Tetrachloride	56-23-5	U	13
Trichloroethene	79-01-6	U	25
1,2-Dichloropropane	78-87-5	U	50
Bromodichloromethane	75-27-4	U	13
2-Chloroethyl vinyl ether	110-75-8	U	500
cis-1,3-Dichloropropene	10061-01-5	U	63
trans-1,3-Dichloropropene	10061-02-6	U	50
1,1,2-Trichloroethane	79-00-5	U	25
Tetrachloroethene	127-18-4	980	38
Dibromochloromethane	124-48-1	U	50
Chlorobenzene	108-90-7	U	25
Bromoform	75-25-2	U	25
1,1,2,2-Tetrachloroethane	79-34-5	U	38
1,3-Dichlorobenzene	541-73-1	U	50
1,4-Dichlorobenzene	106-46-7	U	50
1,2-Dichlorobenzene	95-50-1	U	50

Surrogate Recovery   (1-Chloro-2-Fluoro-Benzene)   :   88%
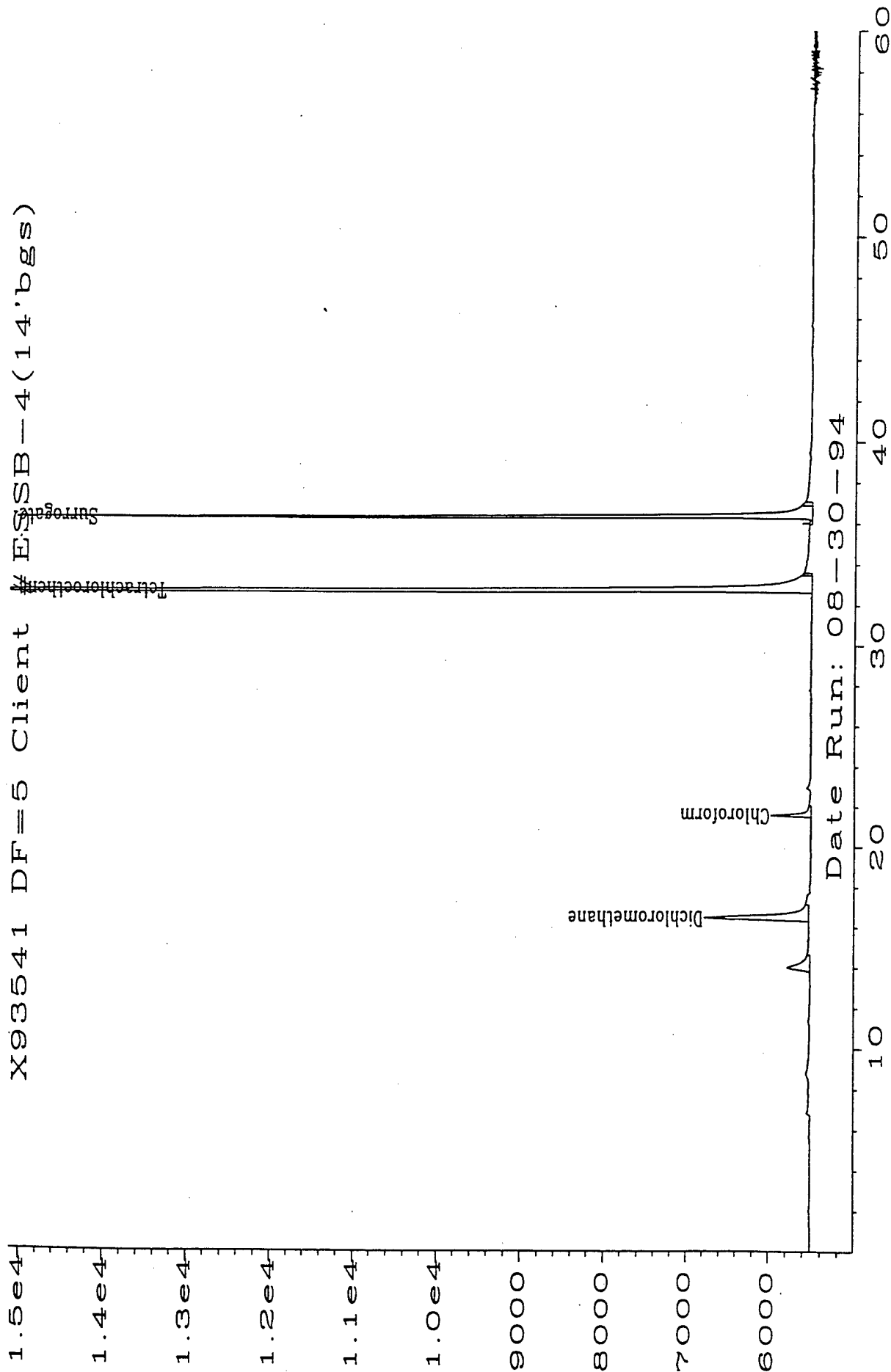
QUALIFIERS:
U = Compound analyzed for, but not detected.
B = Compound in blank and sample. Compare blank and sample date.
EDL = Evergreen's Estimated Detection Limit.

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Analyst

_____
Approved

X93542 DF=125 Client #ESSB-4(21.5'bgs)

Surrogate

Tetrachloroethene

Chloroform

Dichloromethane

Date Run: 09-08-94

Sig. 2 in C:\HPCHEM\2\DATA\HALLO908\006R0101.D

Method 8010 Chlorinated VOC's
Sample Report

Client Sample #	: ESSB-5(2-2.5')	Client Project #	: Battle Creek
Lab Sample #	: X93550	Lab Project #	: 94-3273
Date Sampled	: Not Specified	Matrix	: Soil
Date Received	: 8/29/94	Lab File #	: Hall0830029
Date Prepared	: 8/31/94	Method Blank	: MB083194
Date Analyzed	: 8/31/94	Dilution Factor	: 5.0

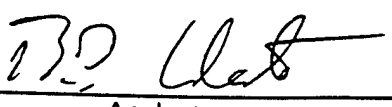| Compound	CAS #	Concentration (ug/Kg)	EDL(ug/Kg)
Dichlorodifluoromethane	75-71-8	U	1
Chloromethane	74-87-3	U	2
Vinyl Chloride	75-01-4	U	1
Bromomethane	74-83-9	U	1
Chloroethane	75-00-3	U	2.5
Trichlorofluoromethane	75-69-4	U	2
1,1-Dichloroethene	75-35-4	U	2
Dichloromethane	75-09-2	11 B	2
trans-1,2-Dichloroethene	156-60-5	U	1
1,1-Dichloroethane	75-34-3	U	1.5
Chloroform	67-66-3	4.5 B	1
1,1,1-Trichloroethane	71-55-6	U	1.5
-Dichloroethane	107-06-2	U	1.5
bon Tetrachloride	56-23-5	U	0.5
Trichloroethene	79-01-6	U	1
1,2-Dichloropropane	78-87-5	U	2
Bromodichloromethane	75-27-4	U	0.5
2-Chloroethyl vinyl ether	110-75-8	U	20
cis-1,3-Dichloropropene	10061-01-5	U	2.5
trans-1,3-Dichloropropene	10061-02-6	U	2
1,1,2-Trichloroethane	79-00-5	U	1
Tetrachloroethene	127-18-4	420	1.5
Dibromochloromethane	124-48-1	U	2
Chlorobenzene	108-90-7	U	1
Bromoform	75-25-2	U	1
1,1,2,2-Tetrachloroethane	79-34-5	U	1.5
1,3-Dichlorobenzene	541-73-1	U	2
1,4-Dichlorobenzene	106-46-7	U	2
1,2-Dichlorobenzene	95-50-1	U	2

Surrogate Recovery   (1-Chloro-2-Fluoro-Benzene)   :   95%

QUALIFIERS:
U = Compound analyzed for, but not detected.
B = Compound in blank and sample. Compare blank and sample date.
EDL = Evergreen's Estimated Detection Limit.

_____
Analyst

_____
Approved

X93550 DF=5 Client # ELSB-5(2-2.5')

Surrogate

Tetrachloroethene

Chloroform

Dichloromethane

Date Run: 08-31-94

10   20   30   40   50   60

1.5e4
1.4e4
1.3e4
1.2e4
1.1e4
1.0e4
9000
8000
7000
6000

Sig. 2 in C:\HPCHEM\2\DATA\HALL0830\029R0101.D

Method 8010 Chlorinated VOC's
Sample Report

Client Sample #	: ESSB-5(14'bgs)	Client Project #	: Battle Creek
Lab Sample #	: X93538	Lab Project #	: 94-3273
Date Sampled	: Not Specified	Matrix	: Soil
Date Received	: 8/29/94	Lab File #	: Hall0830009
Date Prepared	: 8/30/94	Method Blank	: MB083094
Date Analyzed	: 8/30/94	Dilution Factor	: 5.0

Compound	CAS #	Concentration (ug/Kg)	EDL(ug/Kg)
Dichlorodifluoromethane	75-71-8	U	1
Chloromethane	74-87-3	U	2
Vinyl Chloride	75-01-4	U	1
Bromomethane	74-83-9	U	1
Chloroethane	75-00-3	U	2.5
Trichlorofluoromethane	75-69-4	U	2
1,1-Dichloroethene	75-35-4	U	2
Dichloromethane	75-09-2	12 B	2
trans-1,2-Dichloroethene	156-60-5	U	1
1,1-Dichloroethane	75-34-3	U	1.5
Chloroform	67-66-3	3.8 B	1
1,1,1-Trichloroethane	71-55-6	U	1.5
⬤Dichloroethane	107-06-2	U	1.5
⬤on Tetrachloride	56-23-5	U	0.5
Trichloroethene	79-01-6	U	1
1,2-Dichloropropane	78-87-5	U	2
Bromodichloromethane	75-27-4	U	0.5
2-Chloroethyl vinyl ether	110-75-8	U	20
cis-1,3-Dichloropropene	10061-01-5	U	2.5
trans-1,3-Dichloropropene	10061-02-6	U	2
1,1,2-Trichloroethane	79-00-5	U	1
Tetrachloroethene	127-18-4	260	1.5
Dibromochloromethane	124-48-1	U	2
Chlorobenzene	108-90-7	U	1
Bromoform	75-25-2	U	1
1,1,2,2-Tetrachloroethane	79-34-5	U	1.5
1,3-Dichlorobenzene	541-73-1	U	2
1,4-Dichlorobenzene	106-46-7	U	2
1,2-Dichlorobenzene	95-50-1	U	2

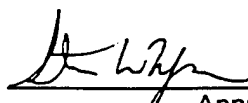Surrogate Recovery (1-Chloro-2-Fluoro-Benzene)　　:　　91%

QUALIFIERS:
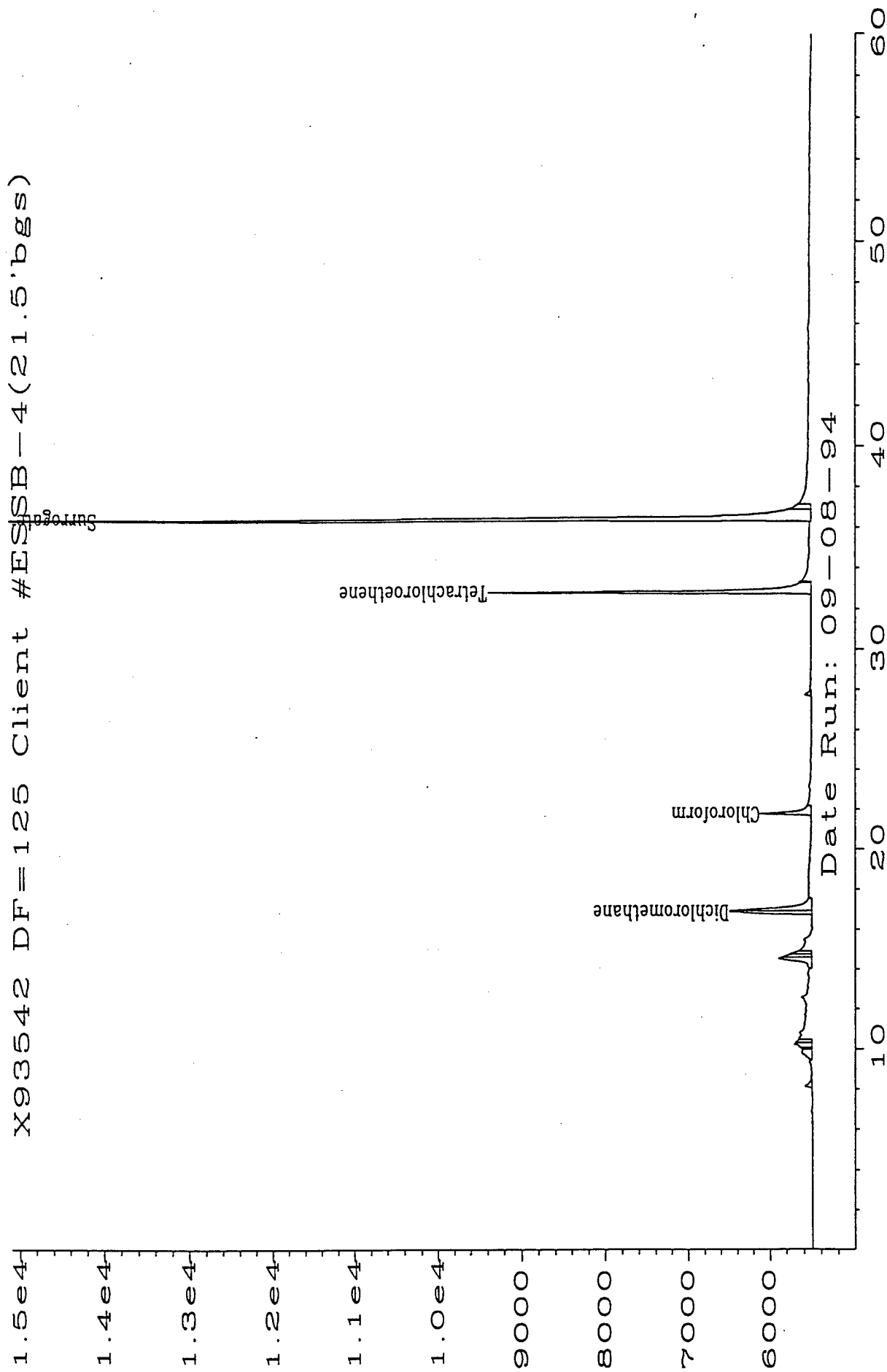U = Compound analyzed for, but not detected.
B = Compound in blank and sample. Compare blank and sample date.
EDL = Evergreen's Estimated Detection Limit.

(signature)	_(signature)_
Analyst	Approved

X93538 DF=5 Client # 0FSSB-5(14'bgs)

![Chromatogram showing peaks labeled Dichloromethane, Chloroform, Tetrachloroethene, and Surrogate. Y-axis ranges from 6000 to 1.5e4 (1.5e4, 1.4e4, 1.3e4, 1.2e4, 1.1e4, 1.0e4, 9000, 8000, 7000, 6000). X-axis ranges from 10 to 60.]

Date Run: 08-30-94

Sig. 2 in C:\HPCHEM\2\DATA\HALLO830\009R0101.D

Method 8010 Chlorinated VOC's
Sample Report

Client Sample #	: ESSB-5(21-21.5')	Client Project #	: Battle Creek
Lab Sample #	: X93551	Lab Project #	: 94-3273
Date Sampled	: Not Specified	Matrix	: Soil
Date Received	: 8/29/94	Lab File #	: Hall0830030
Date Prepared	: 8/31/94	Method Blank	: MB083194
Date Analyzed	: 8/31/94	Dilution Factor	: 1.0

Compound	CAS #	Concentration (ug/Kg)	EDL(ug/Kg)
Dichlorodifluoromethane	75-71-8	U	0.2
Chloromethane	74-87-3	U	0.4
Vinyl Chloride	75-01-4	U	0.2
Bromomethane	74-83-9	U	0.2
Chloroethane	75-00-3	U	0.3
Trichlorofluoromethane	75-69-4	U	0.4
1,1-Dichloroethene	75-35-4	U	0.4
Dichloromethane	75-09-2	2.4 B	0.4
trans-1,2-Dichloroethene	156-60-5	U	0.2
1,1-Dichloroethane	75-34-3	U	0.3
Chloroform	67-66-3	0.9 B	0.2
1,1,1-Trichloroethane	71-55-6	U	0.3
Dichloroethane	107-06-2	U	0.3
Carbon Tetrachloride	56-23-5	U	0.1
Trichloroethene	79-01-6	U	0.2
1,2-Dichloropropane	78-87-5	U	0.4
Bromodichloromethane	75-27-4	U	0.1
2-Chloroethyl vinyl ether	110-75-8	U	4.0
cis-1,3-Dichloropropene	10061-01-5	U	0.5
trans-1,3-Dichloropropene	10061-02-6	U	0.4
1,1,2-Trichloroethane	79-00-5	U	0.2
Tetrachloroethene	127-18-4	60	0.3
Dibromochloromethane	124-48-1	U	0.4
Chlorobenzene	108-90-7	U	0.2
Bromoform	75-25-2	U	0.2
1,1,2,2-Tetrachloroethane	79-34-5	U	0.3
1,3-Dichlorobenzene	541-73-1	U	0.4
1,4-Dichlorobenzene	106-46-7	U	0.4
1,2-Dichlorobenzene	95-50-1	U	0.4

Surrogate Recovery   (1-Chloro-2-Fluoro-Benzene)   :   94%

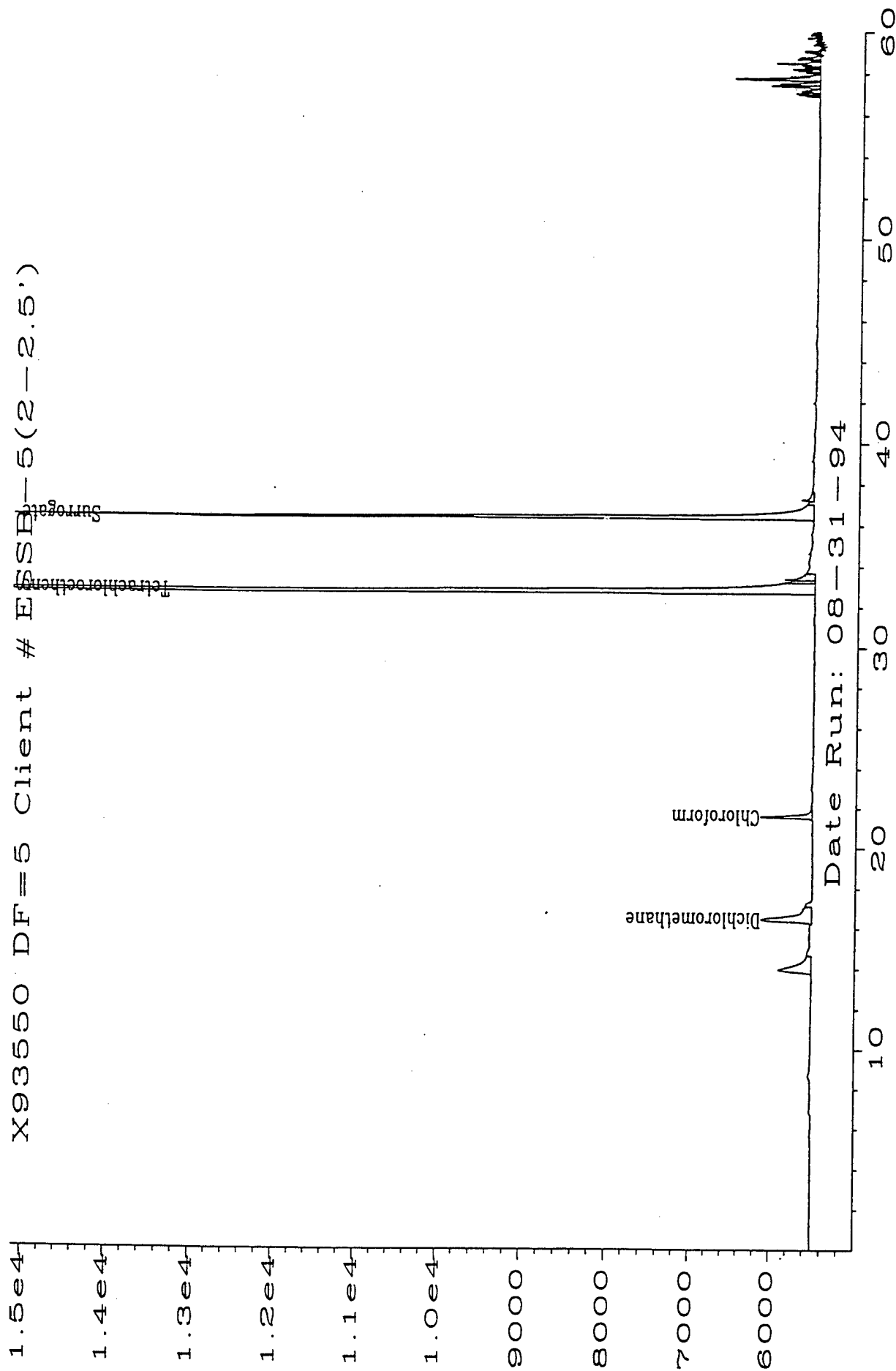QUALIFIERS:
U = Compound analyzed for, but not detected.
B = Compound in blank and sample. Compare blank and sample date.
EDL = Evergreen's Estimated Detection Limit.

_____	_____
Analyst	Approved

X93551 DF=1 Client # ESSB-5(21-21.5')

Surrogate

Tetrachloroethene

Chloroform

Dichloromethane

1.5e4
1.4e4
1.3e4
1.2e4
1.1e4
1.0e4
9000
8000
7000
6000

10   20   30   40   50   60

Date Run: 08-31-94

Sig. 2 in C:\HPCHEM\2\DATA\HALLO830\030R0101.D

EVERGREEN ANALYTICAL, INC.
4036 Youngfield, Wheat Ridge, CO 80033
(303) 425-6021

Method 8010 Chlorinated VOC's
Sample Report

Client Sample #	: ESSB-6(2.75'bgs)	Client Project #	: Battle Creek
Lab Sample #	: X93545	Lab Project #	: 94-3273
Date Sampled	: Not Specified	Matrix	: Soil
Date Received	: 8/29/94	Lab File #	: Hall0830016
Date Prepared	: 8/30/94	Method Blank	: MB083094
Date Analyzed	: 8/31/94	Dilution Factor	: 5.0

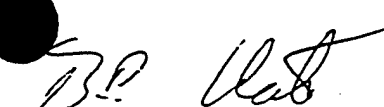| Compound	CAS #	Concentration (ug/Kg)	EDL(ug/Kg)
Dichlorodifluoromethane	75-71-8	U	1
Chloromethane	74-87-3	U	2
Vinyl Chloride	75-01-4	U	1
Bromomethane	74-83-9	U	1
Chloroethane	75-00-3	U	2.5
Trichlorofluoromethane	75-69-4	U	2
1,1-Dichloroethene	75-35-4	U	2
Dichloromethane	75-09-2	22 B	2
trans-1,2-Dichloroethene	156-60-5	U	1
1,1-Dichloroethane	75-34-3	U	1.5
Chloroform	67-66-3	3.5 B	1
1,1,1-Trichloroethane	71-55-6	8.4	1.5
Dichloroethane	107-06-2	U	1.5
Carbon Tetrachloride	56-23-5	U	0.5
Trichloroethene	79-01-6	U	1
1,2-Dichloropropane	78-87-5	U	2
Bromodichloromethane	75-27-4	U	0.5
2-Chloroethyl vinyl ether	110-75-8	U	20
cis-1,3-Dichloropropene	10061-01-5	U	2.5
trans-1,3-Dichloropropene	10061-02-6	U	2
1,1,2-Trichloroethane	79-00-5	U	1
Tetrachloroethene	127-18-4	490	1.5
Dibromochloromethane	124-48-1	U	2
Chlorobenzene	108-90-7	U	1
Bromoform	75-25-2	U	1
1,1,2,2-Tetrachloroethane	79-34-5	U	1.5
1,3-Dichlorobenzene	541-73-1	U	2
1,4-Dichlorobenzene	106-46-7	U	2
1,2-Dichlorobenzene	95-50-1	U	2

Surrogate Recovery (1-Chloro-2-Fluoro-Benzene)   :   76%

QUALIFIERS:
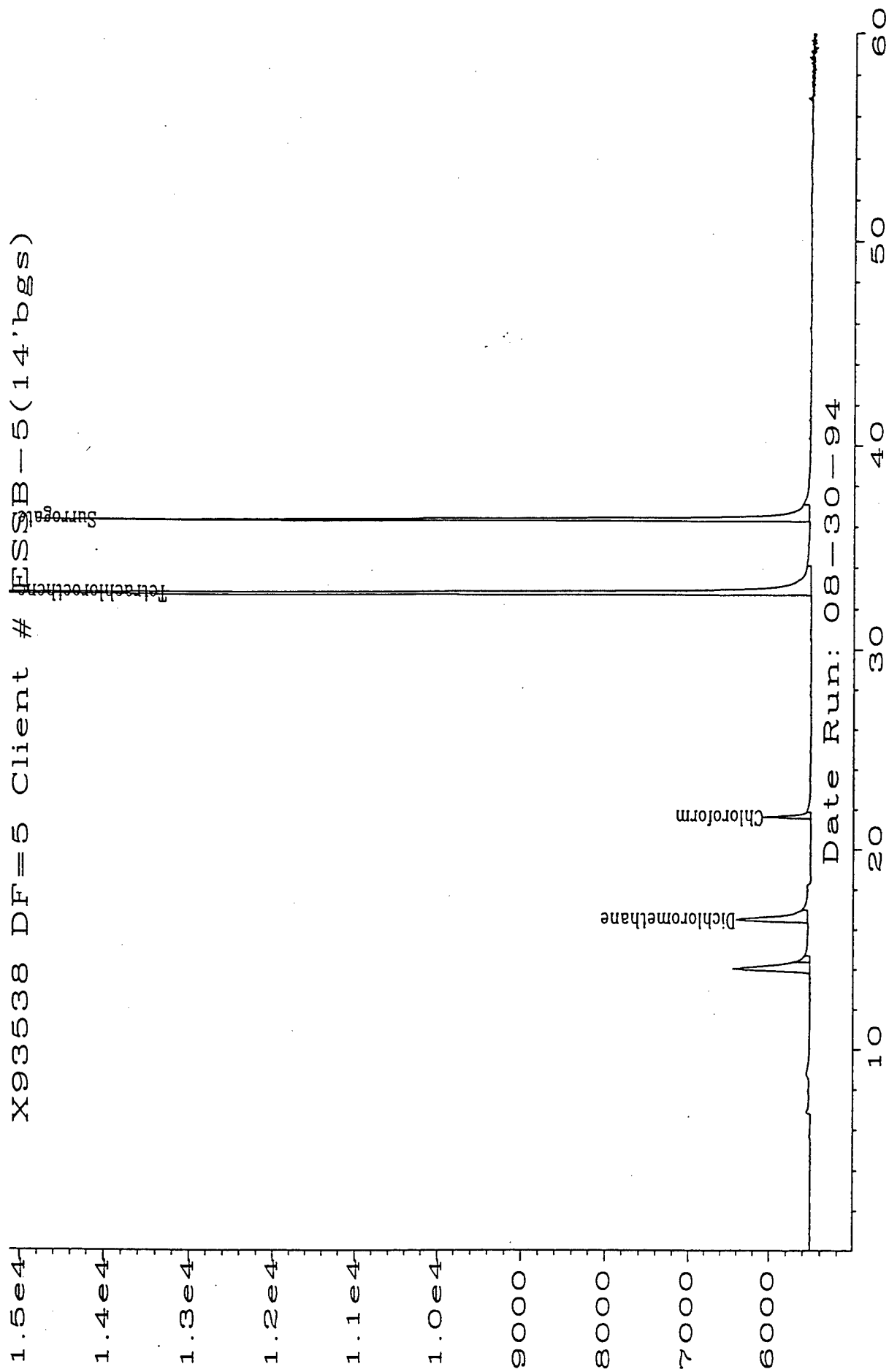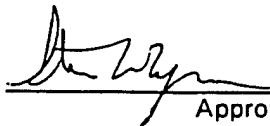U = Compound analyzed for, but not detected.
B = Compound in blank and sample. Compare blank and sample date.
EDL = Evergreen's Estimated Detection Limit.

_____
Analyst

_____
Approved

X93545 DF=5 Client #ESSB-6(2.75'bgs)

Surrogate

Tetrachloroethene

1,1,1-Trichloroethane

Chloroform

Dichloromethane

Date Run: 08-31-94

Sig. 2 in C:\HPCHEM\2\DATA\HALL0830\016R0101.D

Method 8010 Chlorinated VOC's
Sample Report

Client Sample #	: ESSB-6(4-4.5')	Client Project #	: Battle Creek
Lab Sample #	: X93548	Lab Project #	: 94-3273
Date Sampled	: Not Specified	Matrix	: Soil
Date Received	: 8/29/94	Lab File #	: Hall0830019
Date Prepared	: 8/30/94	Method Blank	: MB083094
Date Analyzed	: 8/31/94	Dilution Factor	: 5.0

Compound	CAS #	Concentration (ug/Kg)	EDL(ug/Kg)
Dichlorodifluoromethane	75-71-8	U	1
Chloromethane	74-87-3	U	2
Vinyl Chloride	75-01-4	U	1
Bromomethane	74-83-9	U	1
Chloroethane	75-00-3	U	2.5
Trichlorofluoromethane	75-69-4	U	2
1,1-Dichloroethene	75-35-4	U	2
Dichloromethane	75-09-2	13 B	2
trans-1,2-Dichloroethene	156-60-5	U	1
1,1-Dichloroethane	75-34-3	U	1.5
Chloroform	67-66-3	3.6 B	1
1,1,1-Trichloroethane	71-55-6	U	1.5
Dichloroethane	107-06-2	U	1.5
Carbon Tetrachloride	56-23-5	U	0.5
Trichloroethene	79-01-6	U	1
1,2-Dichloropropane	78-87-5	U	2
Bromodichloromethane	75-27-4	U	0.5
2-Chloroethyl vinyl ether	110-75-8	U	20
cis-1,3-Dichloropropene	10061-01-5	U	2.5
trans-1,3-Dichloropropene	10061-02-6	U	2
1,1,2-Trichloroethane	79-00-5	U	1
Tetrachloroethene	127-18-4	99	1.5
Dibromochloromethane	124-48-1	U	2
Chlorobenzene	108-90-7	U	1
Bromoform	75-25-2	U	1
1,1,2,2-Tetrachloroethane	79-34-5	U	1.5
1,3-Dichlorobenzene	541-73-1	U	2
1,4-Dichlorobenzene	106-46-7	U	2
1,2-Dichlorobenzene	95-50-1	U	2

Surrogate Recovery   (1-Chloro-2-Fluoro-Benzene)   :   87%

QUALIFIERS:
U = Compound analyzed for, but not detected.
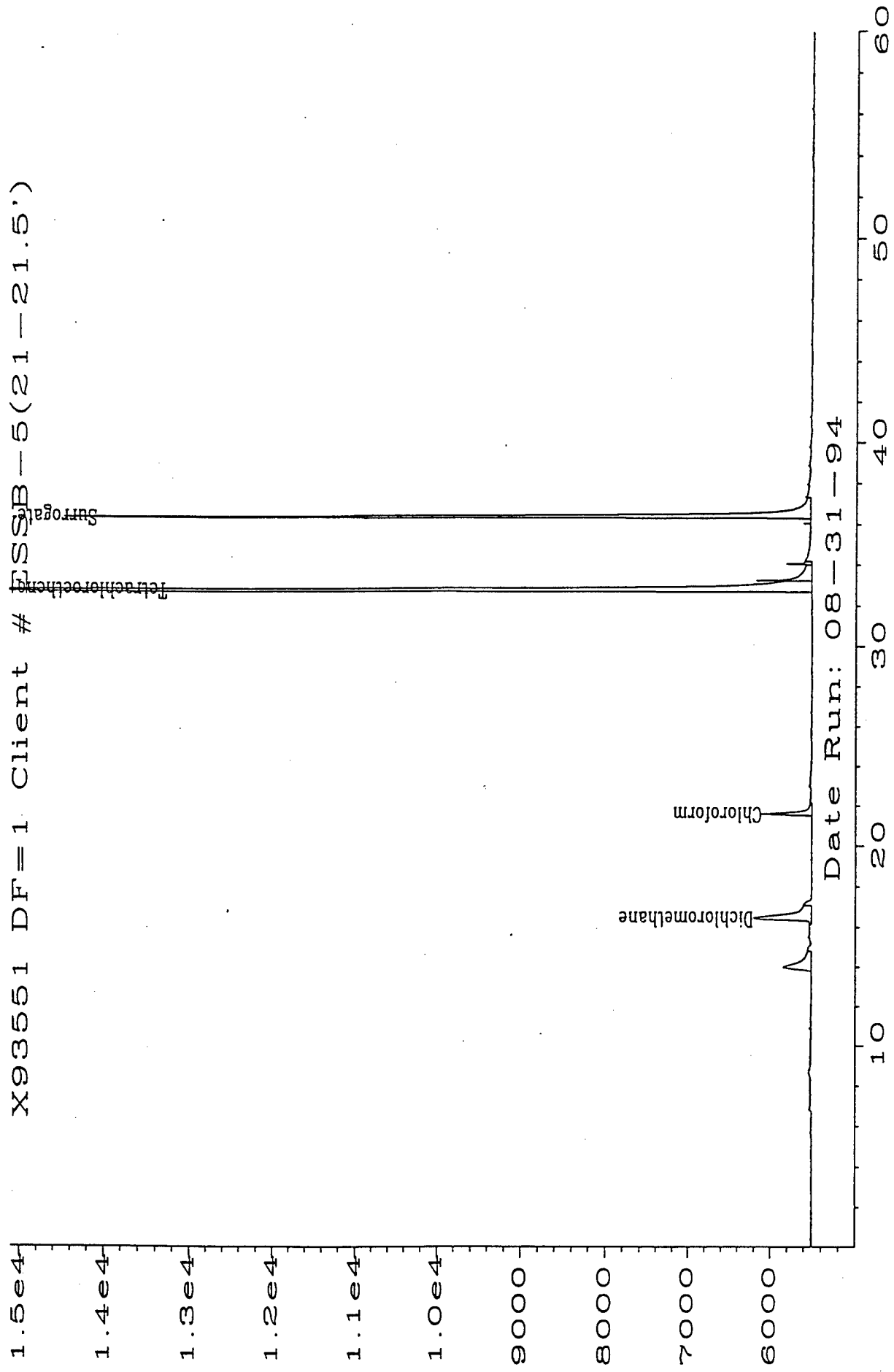B = Compound in blank and sample. Compare blank and sample date.
EDL = Evergreen's Estimated Detection Limit.

_____ Analyst   _____ Approved

X93548 DF=5 Client #

ESSB-6(4-4.5')

Surrogate

Tetrachloroethene

Chloroform

Dichloromethane

Date Run: 08-31-94

1.5e4
1.4e4
1.3e4
1.2e4
1.1e4
1.0e4
9000
8000
7000
6000

10   20   30   40   50   60

Sig. 2 in C:\HPCHEM\2\DATA\HALLO830\019R0101.D

Method 8010 Chlorinated VOC's
Sample Report

Client Sample #	: ESSB-6(13.5-14.25')	Client Project #	: Battle Creek
Lab Sample #	: X93558	Lab Project #	: 94-3273
Date Sampled	: Not Specified	Matrix	: Soil
Date Received	: 8/29/94	Lab File #	: Hall0830037
Date Prepared	: 8/31/94	Method Blank	: MB083194
Date Analyzed	: 9/1/94	Dilution Factor	: 5.0

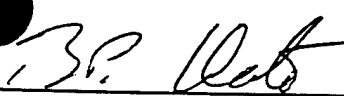| Compound	CAS #	Concentration (ug/Kg)	EDL(ug/Kg)
Dichlorodifluoromethane	75-71-8	U	1
Chloromethane	74-87-3	U	2
Vinyl Chloride	75-01-4	U	1
Bromomethane	74-83-9	U	1
Chloroethane	75-00-3	U	2.5
Trichlorofluoromethane	75-69-4	U	2
1,1-Dichloroethene	75-35-4	U	2
Dichloromethane	75-09-2	22 B	2
trans-1,2-Dichloroethene	156-60-5	U	1
1,1-Dichloroethane	75-34-3	U	1.5
Chloroform	67-66-3	5.3 B	1
1,1,1-Trichloroethane	71-55-6	U	1.5
2-Dichloroethane	107-06-2	U	1.5
Carbon Tetrachloride	56-23-5	U	0.5
Trichloroethene	79-01-6	U	1
1,2-Dichloropropane	78-87-5	U	2
Bromodichloromethane	75-27-4	U	0.5
2-Chloroethyl vinyl ether	110-75-8	U	20
cis-1,3-Dichloropropene	10061-01-5	U	2.5
trans-1,3-Dichloropropene	10061-02-6	U	2
1,1,2-Trichloroethane	79-00-5	U	1
Tetrachloroethene	127-18-4	4.6	1.5
Dibromochloromethane	124-48-1	U	2
Chlorobenzene	108-90-7	U	1
Bromoform	75-25-2	U	1
1,1,2,2-Tetrachloroethane	79-34-5	U	1.5
1,3-Dichlorobenzene	541-73-1	U	2
1,4-Dichlorobenzene	106-46-7	U	2
1,2-Dichlorobenzene	95-50-1	U	2

Surrogate Recovery   (1-Chloro-2-Fluoro-Benzene)   :   74%

QUALIFIERS:
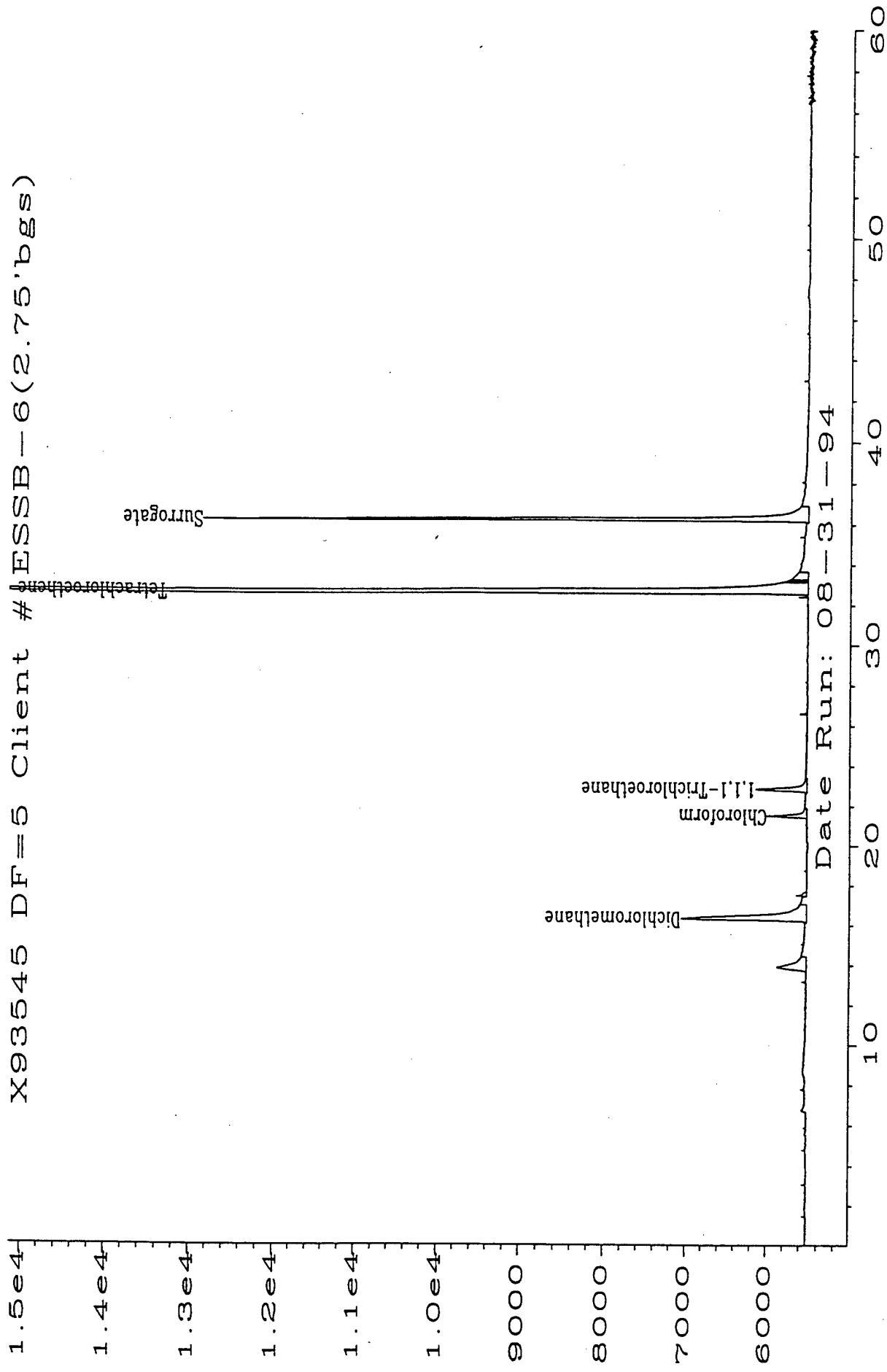U = Compound analyzed for, but not detected.
B = Compound in blank and sample. Compare blank and sample date.
EDL = Evergreen's Estimated Detection Limit.

_____   _____
Analyst   Approved

X93558 DF=5 Client # ESSB-6(13.5-14.25')

Surrogate

Tetrachloroethene

Chloroform

Dichloromethane

Date Run: 09-01-94

1.5e4
1.4e4
1.3e4
1.2e4
1.1e4
1.0e4
9000
8000
7000
6000

10   20   30   40   50   60

Sig. 2 in C:\HPCHEM\2\DATA\HALLO830\O37RO101.D

Method 8010 Chlorinated VOC's
Sample Report

Client Sample #	: ESSB-6(21'bgs)	Client Project #	: Battle Creek
Lab Sample #	: X93544	Lab Project #	: 94-3273
Date Sampled	: Not Specified	Matrix	: Soil
Date Received	: 8/29/94	Lab File #	: Hall0830015
Date Prepared	: 8/30/94	Method Blank	: MB083094
Date Analyzed	: 8/31/94	Dilution Factor	: 5.0

Compound	CAS #	Concentration (ug/Kg)	EDL(ug/Kg)
Dichlorodifluoromethane	75-71-8	U	1
Chloromethane	74-87-3	U	2
Vinyl Chloride	75-01-4	U	1
Bromomethane	74-83-9	U	1
Chloroethane	75-00-3	U	2.5
Trichlorofluoromethane	75-69-4	U	2
1,1-Dichloroethene	75-35-4	U	2
Dichloromethane	75-09-2	2.8 B	2
trans-1,2-Dichloroethene	156-60-5	U	1
1,1-Dichloroethane	75-34-3	U	1.5
Chloroform	67-66-3	2.7 B	1
1,1,1-Trichloroethane	71-55-6	U	1.5
⬤-Dichloroethane	107-06-2	U	1.5
⬤on Tetrachloride	56-23-5	U	0.5
Trichloroethene	79-01-6	U	1
1,2-Dichloropropane	78-87-5	U	2
Bromodichloromethane	75-27-4	U	0.5
2-Chloroethyl vinyl ether	110-75-8	U	20
cis-1,3-Dichloropropene	10061-01-5	U	2.5
trans-1,3-Dichloropropene	10061-02-6	U	2
1,1,2-Trichloroethane	79-00-5	U	1
Tetrachloroethene	127-18-4	6.0	1.5
Dibromochloromethane	124-48-1	U	2
Chlorobenzene	108-90-7	U	1
Bromoform	75-25-2	U	1
1,1,2,2-Tetrachloroethane	79-34-5	U	1.5
1,3-Dichlorobenzene	541-73-1	U	2
1,4-Dichlorobenzene	106-46-7	U	2
1,2-Dichlorobenzene	95-50-1	U	2

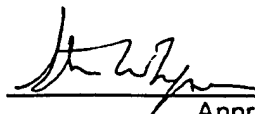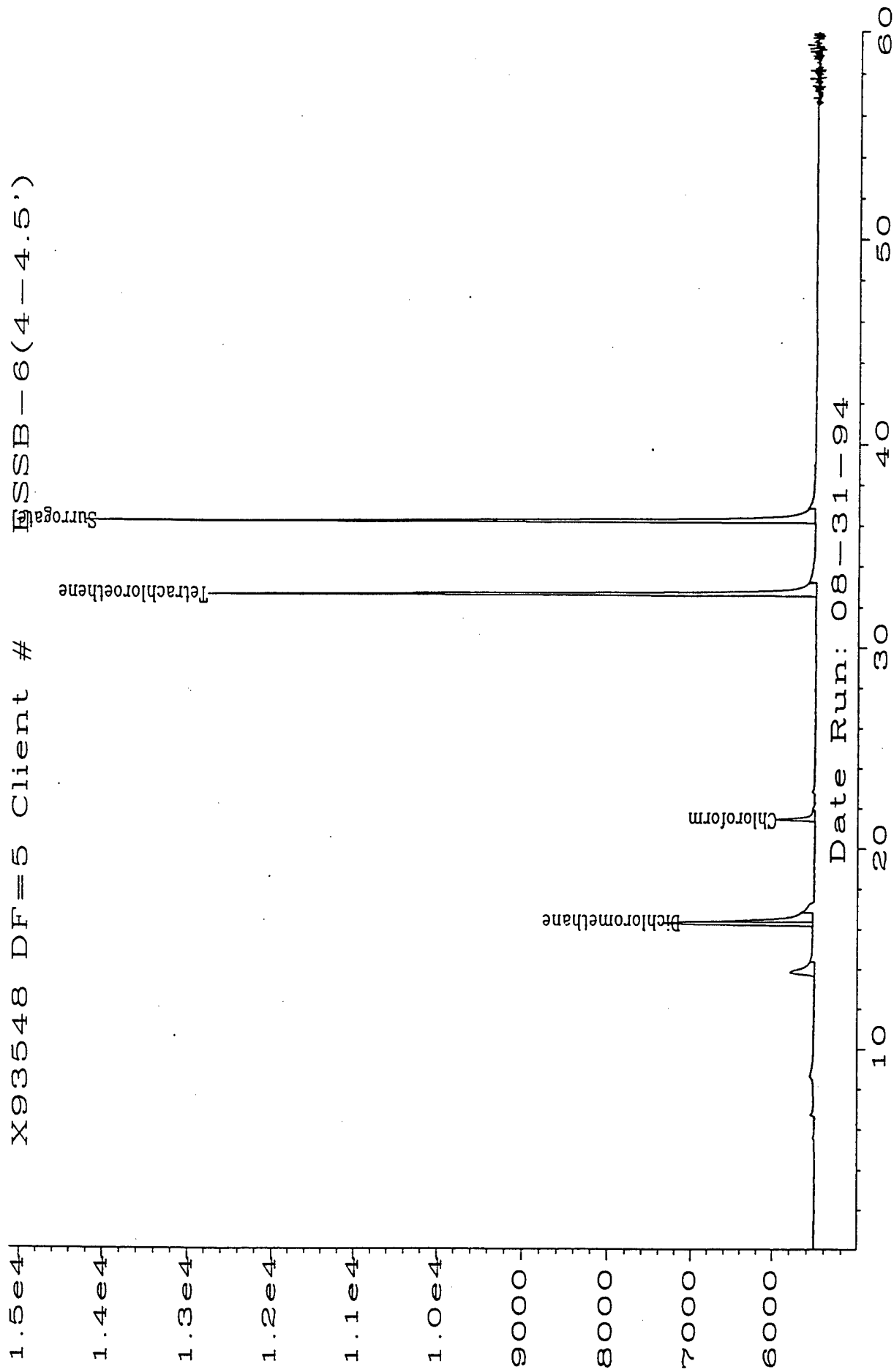Surrogate Recovery (1-Chloro-2-Fluoro-Benzene) : 75%

QUALIFIERS:
U = Compound analyzed for, but not detected.
B = Compound in blank and sample. Compare blank and sample date.
EDL = Evergreen's Estimated Detection Limit.

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Analyst

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Approved

X93544 DF=5 Client # ESSB-6(21'bgs)

Sig. 2 in C:\HPCHEM\2\DATA\HALLO830\O15RO101.D

Date Run: 08-31-94

Peaks labeled: Dichloromethane, Chloroform, Tetrachloroethene, Surrogate

EVERGREEN ANALYTICAL, INC.
4036 Youngfield, Wheat Ridge, CO 80033
(303) 425-6021

Method 8010 Chlorinated VOC's
Sample Report

Client Sample #	: ESSB-6(27-27.5)	Client Project #	: Battle Creek
Lab Sample #	: X93554	Lab Project #	: 94-3273
Date Sampled	: Not Specified	Matrix	: Soil
Date Received	: 8/29/94	Lab File #	: Hall0830033
Date Prepared	: 8/31/94	Method Blank	: MB083194
Date Analyzed	: 8/31/94	Dilution Factor	: 5.0

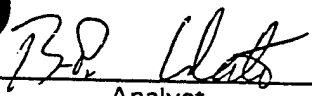| Compound	CAS #	Concentration (ug/Kg)	EDL(ug/Kg)
Dichlorodifluoromethane	75-71-8	U	1
Chloromethane	74-87-3	U	2
Vinyl Chloride	75-01-4	U	1
Bromomethane	74-83-9	U	1
Chloroethane	75-00-3	U	2.5
Trichlorofluoromethane	75-69-4	U	2
1,1-Dichloroethene	75-35-4	U	2
Dichloromethane	75-09-2	9.4 B	2
trans-1,2-Dichloroethene	156-60-5	U	1
1,1-Dichloroethane	75-34-3	U	1.5
Chloroform	67-66-3	6.5 B	1
1,1,1-Trichloroethane	71-55-6	U	1.5
?-Dichloroethane	107-06-2	U	1.5
?bon Tetrachloride	56-23-5	U	0.5
Trichloroethene	79-01-6	U	1
1,2-Dichloropropane	78-87-5	U	2
Bromodichloromethane	75-27-4	U	0.5
2-Chloroethyl vinyl ether	110-75-8	U	20
cis-1,3-Dichloropropene	10061-01-5	U	2.5
trans-1,3-Dichloropropene	10061-02-6	U	2
1,1,2-Trichloroethane	79-00-5	U	1
Tetrachloroethene	127-18-4	39	1.5
Dibromochloromethane	124-48-1	U	2
Chlorobenzene	108-90-7	U	1
Bromoform	75-25-2	U	1
1,1,2,2-Tetrachloroethane	79-34-5	U	1.5
1,3-Dichlorobenzene	541-73-1	U	2
1,4-Dichlorobenzene	106-46-7	U	2
1,2-Dichlorobenzene	95-50-1	U	2

Surrogate Recovery   (1-Chloro-2-Fluoro-Benzene)   :   101%

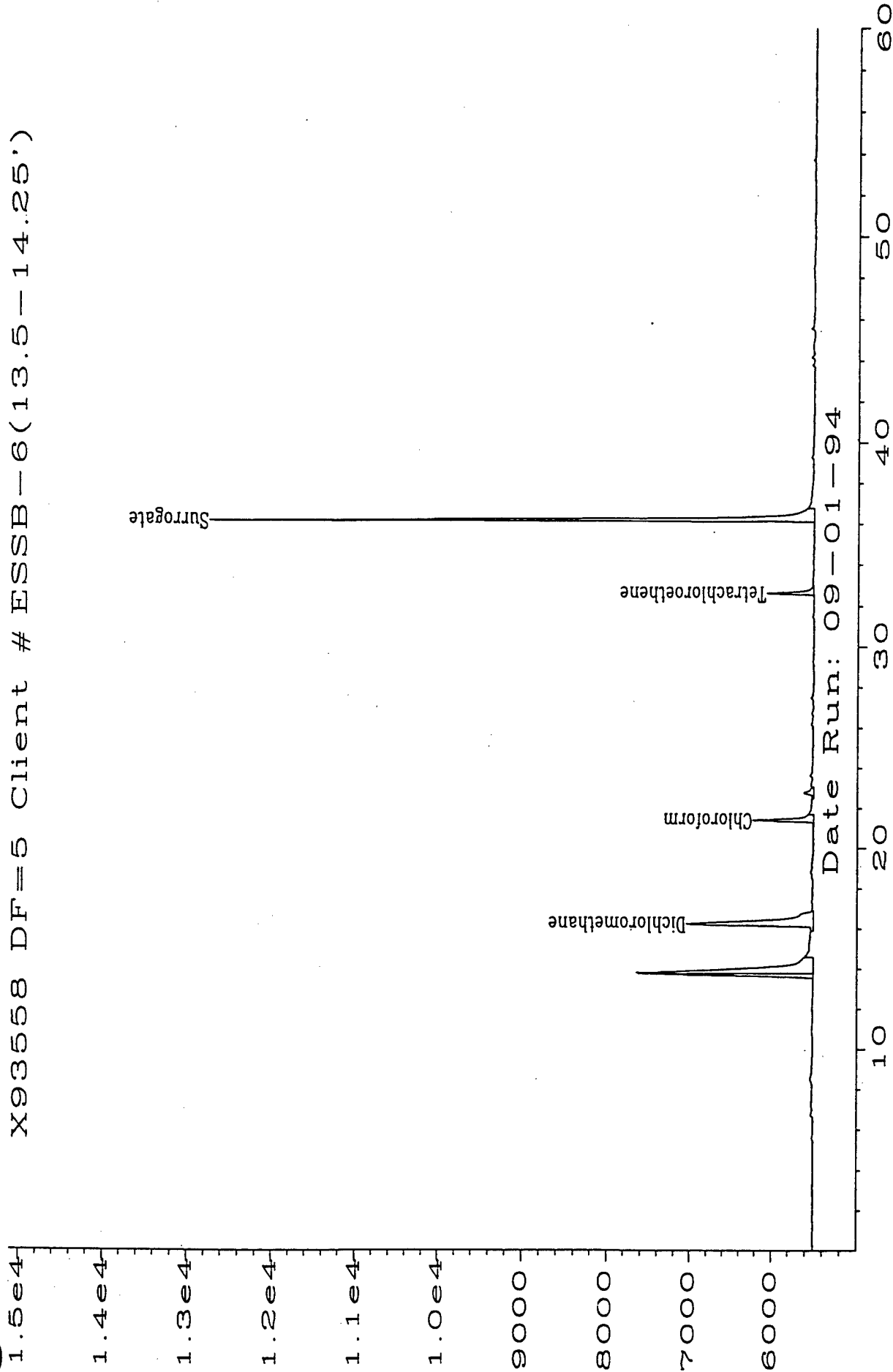QUALIFIERS:
U = Compound analyzed for, but not detected.
B = Compound in blank and sample. Compare blank and sample date.
EDL = Evergreen's Estimated Detection Limit.

_____ Analyst	_____ Approved

X93554 DF=5 Client # ESSB-6(27-27.5)

Surrogate

Tetrachloroethene

Chloroform

Dichloromethane

10   20   30   40   50   60

Date Run: 08-31-94

1.5e4
1.4e4
1.3e4
1.2e4
1.1e4
1.0e4
9000
8000
7000
6000

Sig. 2 in C:\HPCHEM\2\DATA\HALLO830\O33R0101.D

EVERGREEN ANALYTICAL, INC.
4036 Youngfield, Wheat Ridge, CO 80033
(303) 425-6021

Method 8010 Chlorinated VOC's
Sample Report

Client Sample #	: ESSB-7(10-10.5)	Client Project #	: Battle Creek
Lab Sample #	: X93559	Lab Project #	: 94-3273
Date Sampled	: Not Specified	Matrix	: Soil
Date Received	: 8/29/94	Lab File #	: Hall0830038
Date Prepared	: 8/31/94	Method Blank	: MB083194
Date Analyzed	: 9/1/94	Dilution Factor	: 5.0

Compound	CAS #	Concentration (ug/Kg)	EDL(ug/Kg)
Dichlorodifluoromethane	75-71-8	U	1
Chloromethane	74-87-3	U	2
Vinyl Chloride	75-01-4	U	1
Bromomethane	74-83-9	U	1
Chloroethane	75-00-3	U	2.5
Trichlorofluoromethane	75-69-4	U	2
1,1-Dichloroethene	75-35-4	U	2
Dichloromethane	75-09-2	20 B	2
trans-1,2-Dichloroethene	156-60-5	U	1
1,1-Dichloroethane	75-34-3	U	1.5
Chloroform	67-66-3	6.1 B	1
1,1,1-Trichloroethane	71-55-6	2.0	1.5
1,2-Dichloroethane	107-06-2	U	1.5
Carbon Tetrachloride	56-23-5	U	0.5
Trichloroethene	79-01-6	U	1
1,2-Dichloropropane	78-87-5	U	2
Bromodichloromethane	75-27-4	U	0.5
2-Chloroethyl vinyl ether	110-75-8	U	20
cis-1,3-Dichloropropene	10061-01-5	U	2.5
trans-1,3-Dichloropropene	10061-02-6	U	2
1,1,2-Trichloroethane	79-00-5	U	1
Tetrachloroethene	127-18-4	3.7	1.5
Dibromochloromethane	124-48-1	U	2
Chlorobenzene	108-90-7	U	1
Bromoform	75-25-2	U	1
1,1,2,2-Tetrachloroethane	79-34-5	U	1.5
1,3-Dichlorobenzene	541-73-1	U	2
1,4-Dichlorobenzene	106-46-7	U	2
1,2-Dichlorobenzene	95-50-1	U	2

Surrogate Recovery   (1-Chloro-2-Fluoro-Benzene)   :   85%

QUALIFIERS:
U = Compound analyzed for, but not detected.
B = Compound in blank and sample. Compare blank and sample date.
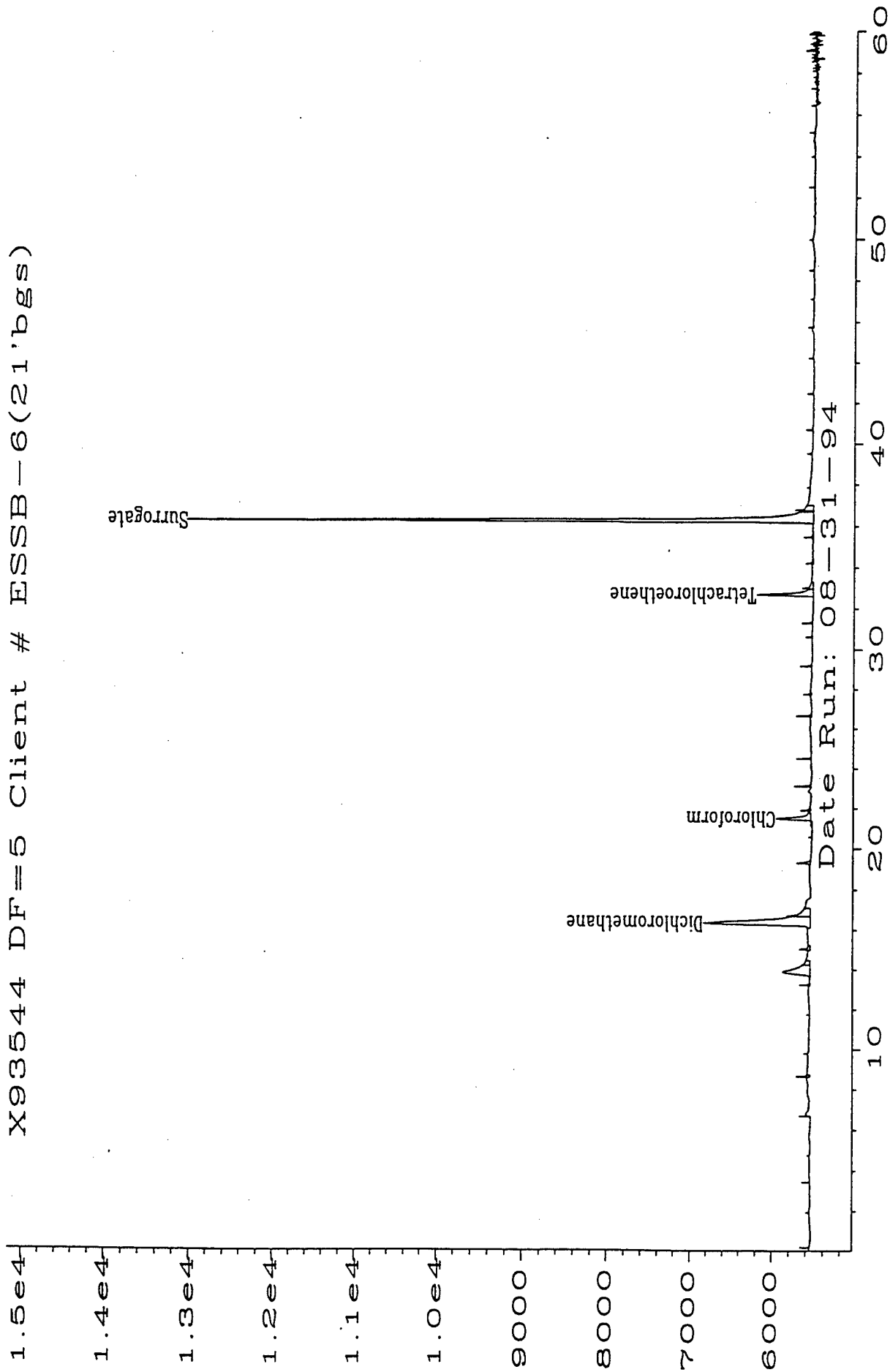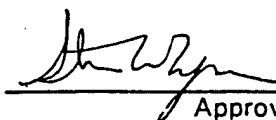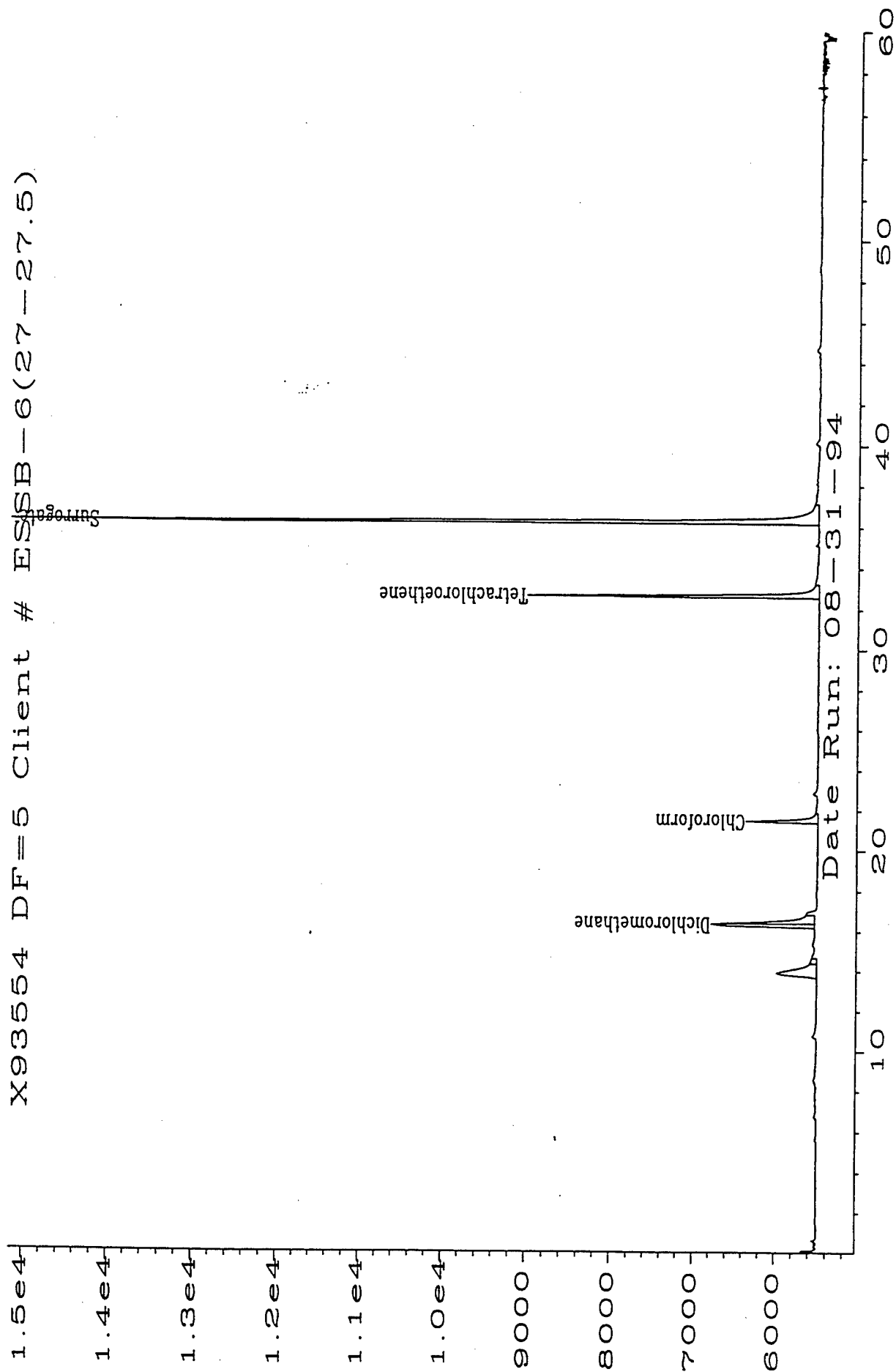EDL = Evergreen's Estimated Detection Limit.

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Analyst

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Approved

X93559 DF=5 Client #ESSB-7(10.0-10.5)
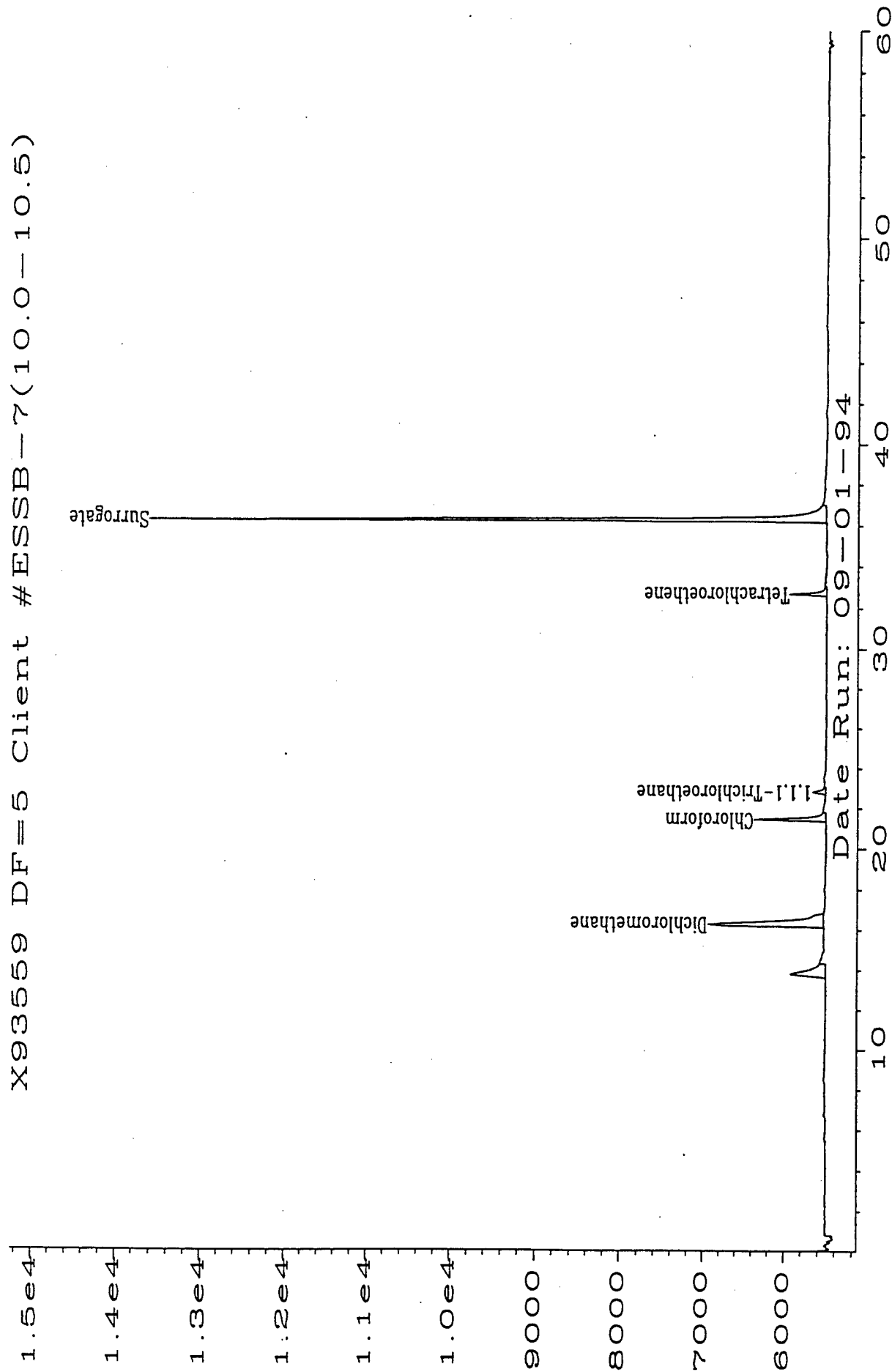
Date Run: 09-01-94

Sig. 2 in C:\HPCHEM\2\DATA\HALLO830\O38RO101.D

EVERGREEN ANALYTICAL, INC.
4036 Youngfield, Wheat Ridge, CO 80033
(303) 425-6021

Method 8010 Chlorinated VOC's
Sample Report

Client Sample #	: ESSB-8(10-10.5)	Client Project #	: Battle Creek
Lab Sample #	: X93555	Lab Project #	: 94-3273
Date Sampled	: Not Specified	Matrix	: Soil
Date Received	: 8/29/94	Lab File #	: Hall0830034
Date Prepared	: 8/31/94	Method Blank	: MB083194
Date Analyzed	: 9/1/94	Dilution Factor	: 5.0

Compound	CAS #	Concentration (ug/Kg)	EDL(ug/Kg)
Dichlorodifluoromethane	75-71-8	U	1
Chloromethane	74-87-3	U	2
Vinyl Chloride	75-01-4	U	1
Bromomethane	74-83-9	U	1
Chloroethane	75-00-3	U	2.5
Trichlorofluoromethane	75-69-4	U	2
1,1-Dichloroethene	75-35-4	U	2
Dichloromethane	75-09-2	18 B	2
trans-1,2-Dichloroethene	156-60-5	U	1
1,1-Dichloroethane	75-34-3	U	1.5
Chloroform	67-66-3	6.6 B	1
1,1,1-Trichloroethane	71-55-6	4.1	1.5
1,2-Dichloroethane	107-06-2	U	1.5
Carbon Tetrachloride	56-23-5	U	0.5
Trichloroethene	79-01-6	U	1
1,2-Dichloropropane	78-87-5	U	2
Bromodichloromethane	75-27-4	U	0.5
2-Chloroethyl vinyl ether	110-75-8	U	20
cis-1,3-Dichloropropene	10061-01-5	U	2.5
trans-1,3-Dichloropropene	10061-02-6	U	2
1,1,2-Trichloroethane	79-00-5	U	1
Tetrachloroethene	127-18-4	4.0	1.5
Dibromochloromethane	124-48-1	U	2
Chlorobenzene	108-90-7	U	1
Bromoform	75-25-2	U	1
1,1,2,2-Tetrachloroethane	79-34-5	U	1.5
1,3-Dichlorobenzene	541-73-1	U	2
1,4-Dichlorobenzene	106-46-7	U	2
1,2-Dichlorobenzene	95-50-1	U	2

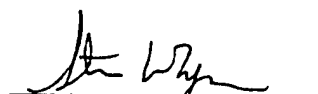Surrogate Recovery   (1-Chloro-2-Fluoro-Benzene)   :   84%

QUALIFIERS:
U = Compound analyzed for, but not detected.
B = Compound in blank and sample. Compare blank and sample date.
EDL = Evergreen's Estimated Detection Limit.

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Analyst

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Approved

X93555 DF=5 Client # ESSB-8(10-10.5)

Surrogate

Tetrachloroethene

1,1,1-Trichloroethane

Chloroform

Dichloromethane

Date Run: 09-01-94

Sig. 2 in C:\HPCHEM\2\DATA\HALLO830\O34R0101.D

Method 8010 Chlorinated VOC's
Sample Report

Client Sample #	: ESSB-9(10-11.5')	Client Project #	: Battle Creek
Lab Sample #	: X93553	Lab Project #	: 94-3273
Date Sampled	: Not Specified	Matrix	: Soil
Date Received	: 8/29/94	Lab File #	: Hall0830032
Date Prepared	: 8/31/94	Method Blank	: MB083194
Date Analyzed	: 8/31/94	Dilution Factor	: 5.0

Compound	CAS #	Concentration (ug/Kg)	EDL(ug/Kg)
Dichlorodifluoromethane	75-71-8	U	1
Chloromethane	74-87-3	U	2
Vinyl Chloride	75-01-4	U	1
Bromomethane	74-83-9	U	1
Chloroethane	75-00-3	U	2.5
Trichlorofluoromethane	75-69-4	U	2
1,1-Dichloroethene	75-35-4	U	2
Dichloromethane	75-09-2	12 B	2
trans-1,2-Dichloroethene	156-60-5	U	1
1,1-Dichloroethane	75-34-3	U	1.5
Chloroform	67-66-3	5.6 B	1
1,1,1-Trichloroethane	71-55-6	4.7	1.5
Dichloroethane	107-06-2	U	1.5
Carbon Tetrachloride	56-23-5	U	0.5
Trichloroethene	79-01-6	U	1
1,2-Dichloropropane	78-87-5	U	2
Bromodichloromethane	75-27-4	U	0.5
2-Chloroethyl vinyl ether	110-75-8	U	20
cis-1,3-Dichloropropene	10061-01-5	U	2.5
trans-1,3-Dichloropropene	10061-02-6	U	2
1,1,2-Trichloroethane	79-00-5	U	1
Tetrachloroethene	127-18-4	7.5	1.5
Dibromochloromethane	124-48-1	U	2
Chlorobenzene	108-90-7	U	1
Bromoform	75-25-2	U	1
1,1,2,2-Tetrachloroethane	79-34-5	U	1.5
1,3-Dichlorobenzene	541-73-1	U	2
1,4-Dichlorobenzene	106-46-7	U	2
1,2-Dichlorobenzene	95-50-1	U	2

Surrogate Recovery   (1-Chloro-2-Fluoro-Benzene)   :   82%

QUALIFIERS:
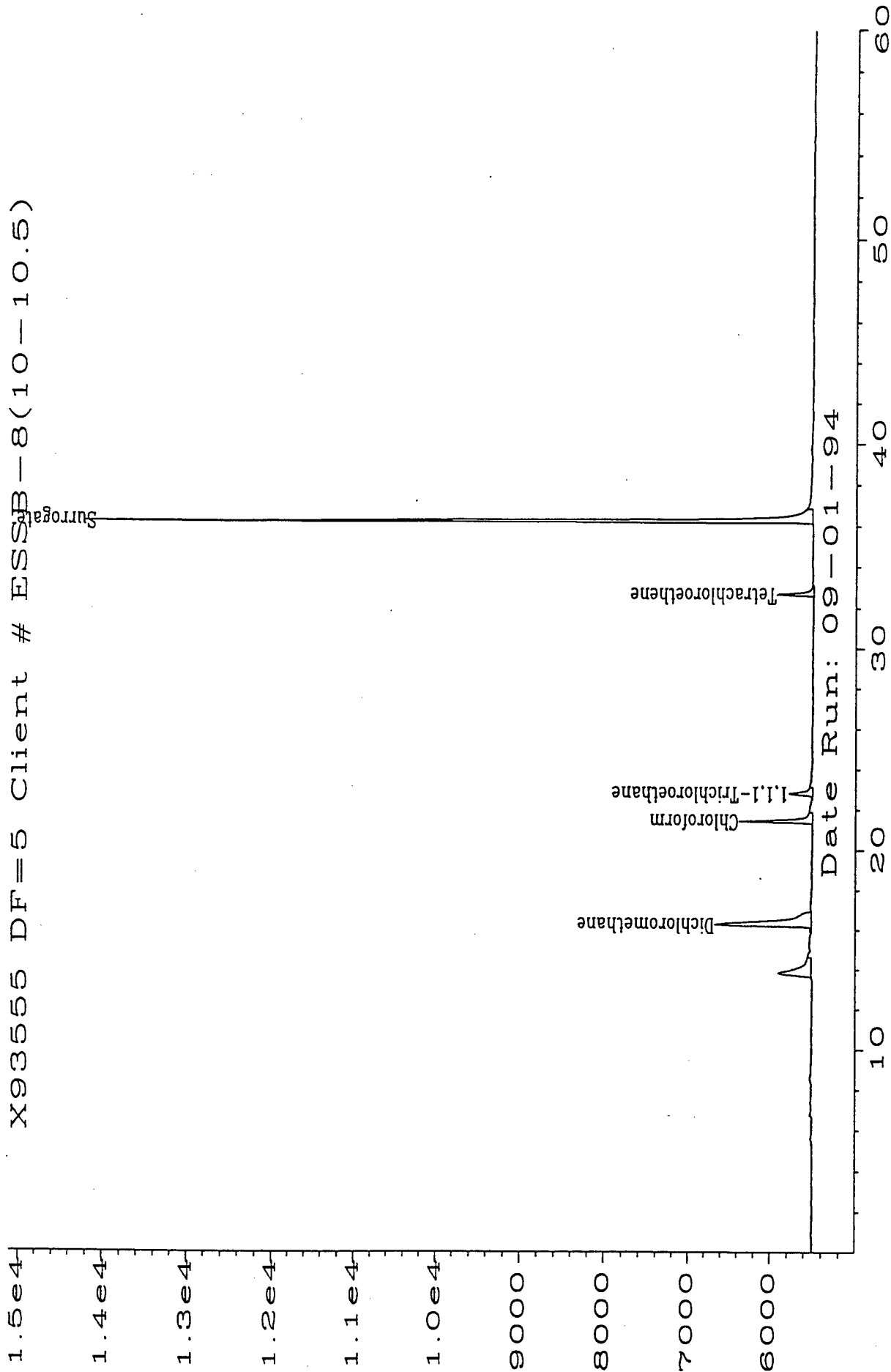U = Compound analyzed for, but not detected.
B = Compound in blank and sample. Compare blank and sample date.
EDL = Evergreen's Estimated Detection Limit.

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Analyst

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Approved

X93553 DF=5 Client # ESSB-9(10-11.5')

Surrogate

Tetrachloroethene

1,1,1-Trichloroethane
Chloroform

Dichloromethane

1.5e4
1.4e4
1.3e4
1.2e4
1.1e4
1.0e4
9000
8000
7000
6000

10   20   30   40   50   60

Date Run: 08-31-94

Sig. 2 in C:\HPCHEM\2\DATA\HALL0830\032R0101.D

EVERGREEN ANALYTICAL, INC.
4036 Youngfield, Wheat Ridge, CO 80033
(303) 425-6021

Method 8010 Chlorinated VOC's
Sample Report

Client Sample #	: ESSB-10(5-5.5')	Client Project #	: Battle Creek
Lab Sample #	: X93556	Lab Project #	: 94-3273
Date Sampled	: Not Specified	Matrix	: Soil
Date Received	: 8/29/94	Lab File #	: Hall0830035
Date Prepared	: 8/31/94	Method Blank	: MB083194
Date Analyzed	: 9/1/94	Dilution Factor	: 5.0

Compound	CAS #	Concentration (ug/Kg)	EDL(ug/Kg)
Dichlorodifluoromethane	75-71-8	U	1
Chloromethane	74-87-3	U	2
Vinyl Chloride	75-01-4	U	1
Bromomethane	74-83-9	U	1
Chloroethane	75-00-3	U	2.5
Trichlorofluoromethane	75-69-4	U	2
1,1-Dichloroethene	75-35-4	U	2
Dichloromethane	75-09-2	9.2 B	2
trans-1,2-Dichloroethene	156-60-5	U	1
1,1-Dichloroethane	75-34-3	U	1.5
Chloroform	67-66-3	7.0 B	1
1,1,1-Trichloroethane	71-55-6	U	1.5
2-Dichloroethane	107-06-2	U	1.5
bon Tetrachloride	56-23-5	U	0.5
Trichloroethene	79-01-6	U	1
1,2-Dichloropropane	78-87-5	U	2
Bromodichloromethane	75-27-4	U	0.5
2-Chloroethyl vinyl ether	110-75-8	U	20
cis-1,3-Dichloropropene	10061-01-5	U	2.5
trans-1,3-Dichloropropene	10061-02-6	U	2
1,1,2-Trichloroethane	79-00-5	U	1
Tetrachloroethene	127-18-4	23	1.5
Dibromochloromethane	124-48-1	U	2
Chlorobenzene	108-90-7	U	1
Bromoform	75-25-2	U	1
1,1,2,2-Tetrachloroethane	79-34-5	U	1.5
1,3-Dichlorobenzene	541-73-1	U	2
1,4-Dichlorobenzene	106-46-7	U	2
1,2-Dichlorobenzene	95-50-1	U	2

Surrogate Recovery   (1-Chloro-2-Fluoro-Benzene)   :   96%

QUALIFIERS:
U = Compound analyzed for, but not detected.
B = Compound in blank and sample. Compare blank and sample date.
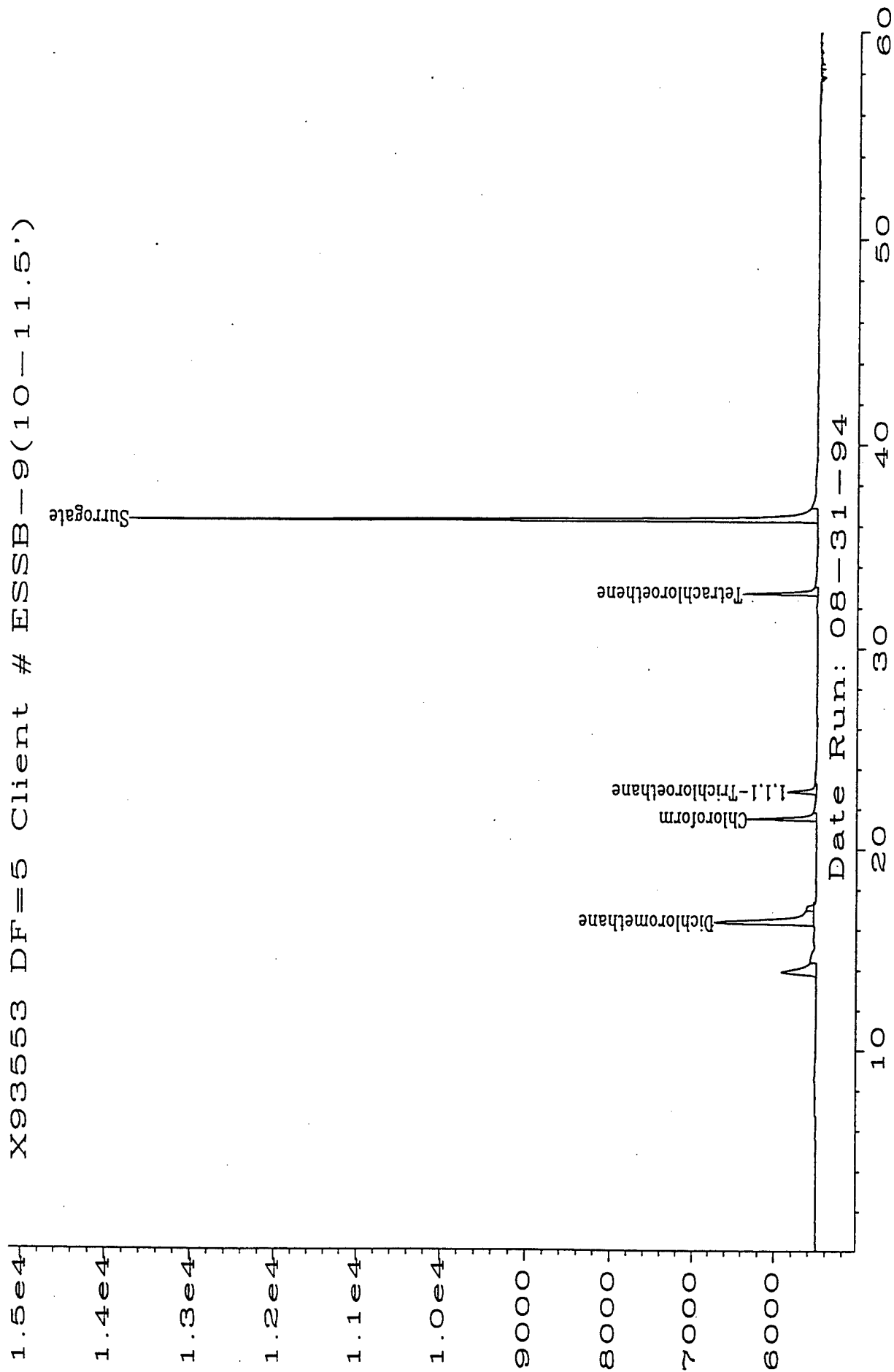EDL = Evergreen's Estimated Detection Limit.

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Analyst

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Approved

X93556 DF=5 Client # ESSB-10(5-5.5')

Surrogate

Tetrachloroethene

Chloroform

Dichloromethane

Date Run: 09-01-94

10   20   30   40   50   60

1.5e4
1.4e4
1.3e4
1.2e4
1.1e4
1.0e4
9000
8000
7000
6000

Sig. 2 in C:\HPCHEM\2\DATA\HALL0830\035R0101.D

EVERGREEN ANALYTICAL, INC.
4036 Youngfield, Wheat Ridge, CO 80033
(303) 425-6021

Method 8010 Chlorinated VOC's
Sample Report

Client Sample #	: ESSB-10(18.5-19.0')	Client Project #	: Battle Creek
Lab Sample #	: X93557	Lab Project #	: 94-3273
Date Sampled	: Not Specified	Matrix	: Soil
Date Received	: 8/29/94	Lab File #	: Hall0830036
Date Prepared	: 8/31/94	Method Blank	: MB083194
Date Analyzed	: 9/1/94	Dilution Factor	: 5.0

Compound	CAS #	Concentration (ug/Kg)	EDL(ug/Kg)
Dichlorodifluoromethane	75-71-8	U	1
Chloromethane	74-87-3	U	2
Vinyl Chloride	75-01-4	U	1
Bromomethane	74-83-9	U	1
Chloroethane	75-00-3	U	2.5
Trichlorofluoromethane	75-69-4	U	2
1,1-Dichloroethene	75-35-4	U	2
Dichloromethane	75-09-2	22 B	2
trans-1,2-Dichloroethene	156-60-5	U	1
1,1-Dichloroethane	75-34-3	U	1.5
Chloroform	67-66-3	6.0 B	1
1,1,1-Trichloroethane	71-55-6	U	1.5
1,2-Dichloroethane	107-06-2	U	1.5
Carbon Tetrachloride	56-23-5	U	0.5
Trichloroethene	79-01-6	U	1
1,2-Dichloropropane	78-87-5	U	2
Bromodichloromethane	75-27-4	U	0.5
2-Chloroethyl vinyl ether	110-75-8	U	20
cis-1,3-Dichloropropene	10061-01-5	U	2.5
trans-1,3-Dichloropropene	10061-02-6	U	2
1,1,2-Trichloroethane	79-00-5	U	1
Tetrachloroethene	127-18-4	11	1.5
Dibromochloromethane	124-48-1	U	2
Chlorobenzene	108-90-7	U	1
Bromoform	75-25-2	U	1
1,1,2,2-Tetrachloroethane	79-34-5	U	1.5
1,3-Dichlorobenzene	541-73-1	U	2
1,4-Dichlorobenzene	106-46-7	U	2
1,2-Dichlorobenzene	95-50-1	U	2

Surrogate Recovery   (1-Chloro-2-Fluoro-Benzene)   :   88%

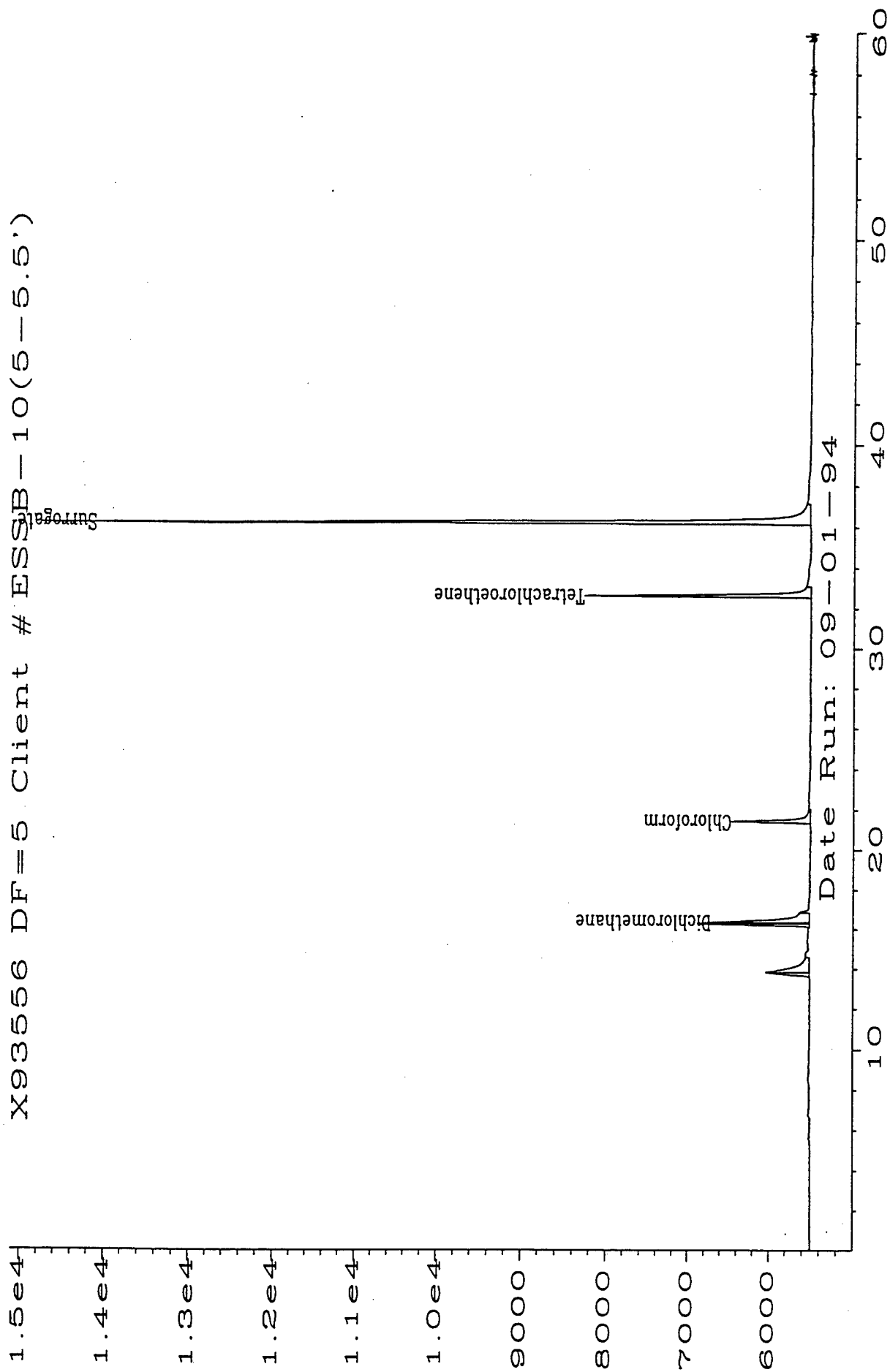QUALIFIERS:
U = Compound analyzed for, but not detected.
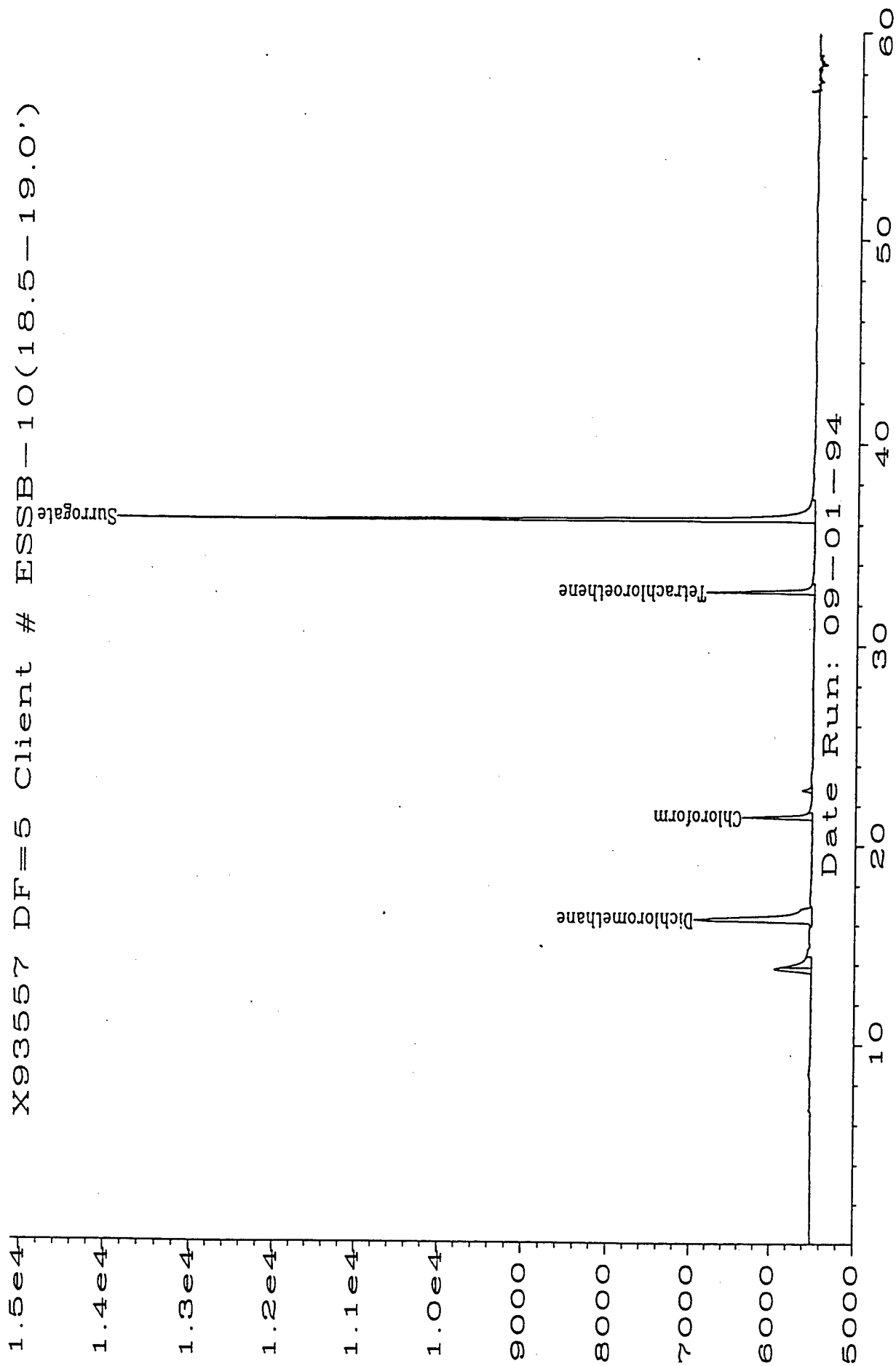B = Compound in blank and sample. Compare blank and sample date.
EDL = Evergreen's Estimated Detection Limit.

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Analyst

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Approved

X93557 DF=5 Client # ESSB-10(18.5-19.0')

Surrogate

Tetrachloroethene

Chloroform

Dichloromethane

Date Run: 09-01-94

1.5e4
1.4e4
1.3e4
1.2e4
1.1e4
1.0e4
9000
8000
7000
6000
5000

10 20 30 40 50 60

Sig. 2 in C:\HPCHEM\2\DATA\HALL0830\036R0101.D

Method 8010 Chlorinated VOC's
Method Blank Report

Method Blank	: MB083094	Client Project #	: Battle Creek
Date Prepared	: 8/30/94	Lab Project #	: 94-3273
Date Analyzed	: 8/30/94	Matrix	: Water
		Lab File #	: Hall0830006

Compound	CAS #	Concentration (ug/L)	EDL(ug/L)
Dichlorodifluoromethane	75-71-8	U	0.2
Chloromethane	74-87-3	U	0.4
Vinyl Chloride	75-01-4	U	0.2
Bromomethane	74-83-9	U	0.2
Chloroethane	75-00-3	U	0.5
Trichlorofluoromethane	75-69-4	U	0.4
1,1-Dichloroethene	75-35-4	U	0.4
Dichloromethane	75-09-2	2.5	0.4
trans-1,2-Dichloroethene	156-60-5	U	0.2
1,1-Dichloroethane	75-34-3	U	0.3
Chloroform	67-66-3	1.2	0.2
1,1,1-Trichloroethane	71-55-6	U	0.3
1,2-Dichloroethane	107-06-2	U	0.3
Carbon Tetrachloride	56-23-5	U	0.1
Trichloroethene	79-01-6	U	0.2
1,2-Dichloropropane	78-87-5	U	0.4
Bromodichloromethane	75-27-4	U	0.1
2-Chloroethyl vinyl ether	110-75-8	U	4.0
cis-1,3-Dichloropropene	10061-01-5	U	0.5
trans-1,3-Dichloropropene	10061-02-6	U	0.4
1,1,2-Trichloroethane	79-00-5	U	0.2
Tetrachloroethene	127-18-4	U	0.3
Dibromochloromethane	124-48-1	U	0.4
Chlorobenzene	108-90-7	U	0.2
Bromoform	75-25-2	U	0.2
1,1,2,2-Tetrachloroethane	79-34-5	U	0.3
1,3-Dichlorobenzene	541-73-1	U	0.4
1,4-Dichlorobenzene	106-46-7	U	0.4
1,2-Dichlorobenzene	95-50-1	U	0.4

Surrogate Recovery   (1-Chloro-2-Fluoro-Benzene)   :   110%

QUALIFIERS:
U = Compound analyzed for, but not detected.
B = Compound in blank and sample. Compare blank and sample date.
EDL = Evergreen's Estimated Detection Limit.

_____
Analyst

_____
Approved

MB083094 Method Blank

Surrogate

Chloroform

Dichloromethane

1.5e4
1.4e4
1.3e4
1.2e4
1.1e4
1.0e4
9000
8000
7000
6000

10   20   30   40   50   60

Date Run: 08-30-94

Sig. 2 in C:\HPCHEM\2\DATA\HALL0830\006R0101.D

EVERGREEN ANALYTICAL, INC.
4036 Youngfield, Wheat Ridge, CO 80033
(303) 425-6021

Method 8010 Chlorinated VOC's
Method Blank Report

Method Blank	: MB083194	Client Project #	: Battle Creek
Date Prepared	: 8/31/94	Lab Project #	: 94-3273
Date Analyzed	: 8/31/94	Matrix	: Water
		Lab File #	: Hall0830023

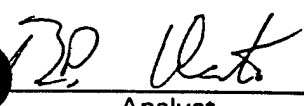| Compound	CAS #	Concentration (ug/L)	EDL(ug/L)
Dichlorodifluoromethane	75-71-8	U	0.2
Chloromethane	74-87-3	U	0.4
Vinyl Chloride	75-01-4	U	0.2
Bromomethane	74-83-9	U	0.2
Chloroethane	75-00-3	U	0.5
Trichlorofluoromethane	75-69-4	U	0.4
1,1-Dichloroethene	75-35-4	U	0.4
Dichloromethane	75-09-2	2.3	0.4
trans-1,2-Dichloroethene	156-60-5	U	0.2
1,1-Dichloroethane	75-34-3	U	0.3
Chloroform	67-66-3	0.8	0.2
1,1,1-Trichloroethane	71-55-6	U	0.3
1,2-Dichloroethane	107-06-2	U	0.3
Carbon Tetrachloride	56-23-5	U	0.1
Trichloroethene	79-01-6	U	0.2
1,2-Dichloropropane	78-87-5	U	0.4
Bromodichloromethane	75-27-4	U	0.1
2-Chloroethyl vinyl ether	110-75-8	U	4.0
cis-1,3-Dichloropropene	10061-01-5	U	0.5
trans-1,3-Dichloropropene	10061-02-6	U	0.4
1,1,2-Trichloroethane	79-00-5	U	0.2
Tetrachloroethene	127-18-4	U	0.3
Dibromochloromethane	124-48-1	U	0.4
Chlorobenzene	108-90-7	U	0.2
Bromoform	75-25-2	U	0.2
1,1,2,2-Tetrachloroethane	79-34-5	U	0.3
1,3-Dichlorobenzene	541-73-1	U	0.4
1,4-Dichlorobenzene	106-46-7	U	0.4
1,2-Dichlorobenzene	95-50-1	U	0.4

Surrogate Recovery   (1-Chloro-2-Fluoro-Benzene)   :   78%

QUALIFIERS:
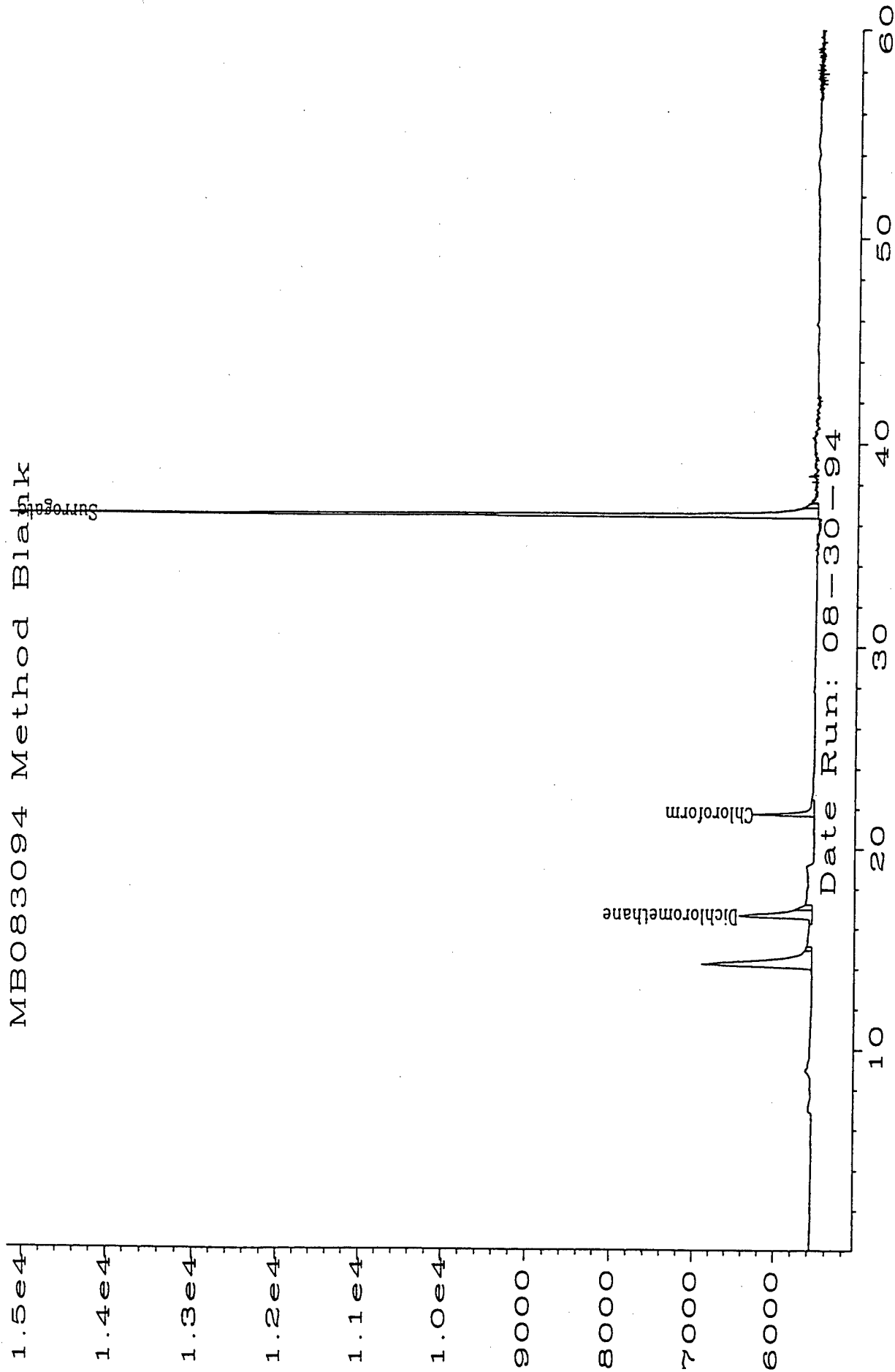U = Compound analyzed for, but not detected.
B = Compound in blank and sample. Compare blank and sample date.
EDL = Evergreen's Estimated Detection Limit.

_____   _____
Analyst   Approved

MB083194 Method Blank
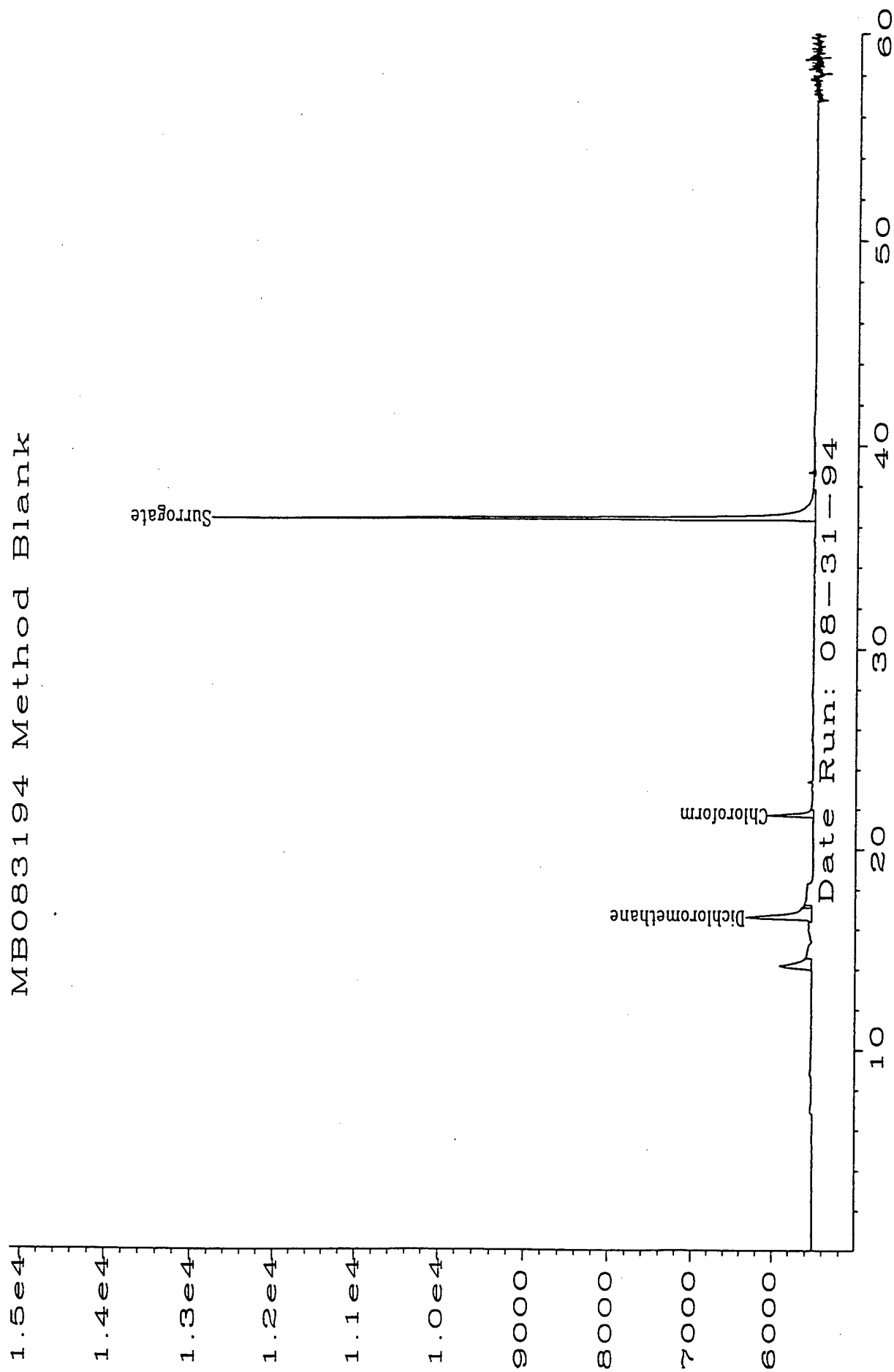
Dichloromethane

Chloroform

Surrogate

Date Run: 08-31-94

Sig. 2 in C:\HPCHEM\2\DATA\HALLO830\O23RO1O1.D

Method 8010 Chlorinated VOC's
Method Blank Report

Method Blank	: MEB090894	Client Project #	: Battle Creek
Date Prepared	: 9/8/94	Lab Project #	: 94-3273
Date Analyzed	: 9/8/94	Matrix	: Water
		Lab File #	: Hall0908005

Compound	CAS #	Concentration (ug/L)	EDL(ug/L)
Dichlorodifluoromethane	75-71-8	U	0.2
Chloromethane	74-87-3	U	0.4
Vinyl Chloride	75-01-4	U	0.2
Bromomethane	74-83-9	U	0.2
Chloroethane	75-00-3	U	0.5
Trichlorofluoromethane	75-69-4	U	0.4
1,1-Dichloroethene	75-35-4	U	0.4
Dichloromethane	75-09-2	2.0	0.4
trans-1,2-Dichloroethene	156-60-5	U	0.2
1,1-Dichloroethane	75-34-3	U	0.3
Chloroform	67-66-3	1.1	0.2
1,1,1-Trichloroethane	71-55-6	U	0.3
1,2-Dichloroethane	107-06-2	U	0.3
Carbon Tetrachloride	56-23-5	U	0.1
Trichloroethene	79-01-6	U	0.2
1,2-Dichloropropane	78-87-5	U	0.4
Bromodichloromethane	75-27-4	U	0.1
2-Chloroethyl vinyl ether	110-75-8	U	4.0
cis-1,3-Dichloropropene	10061-01-5	U	0.5
trans-1,3-Dichloropropene	10061-02-6	U	0.4
1,1,2-Trichloroethane	79-00-5	U	0.2
Tetrachloroethene	127-18-4	U	0.3
Dibromochloromethane	124-48-1	U	0.4
Chlorobenzene	108-90-7	U	0.2
Bromoform	75-25-2	U	0.2
1,1,2,2-Tetrachloroethane	79-34-5	U	0.3
1,3-Dichlorobenzene	541-73-1	U	0.4
1,4-Dichlorobenzene	106-46-7	U	0.4
1,2-Dichlorobenzene	95-50-1	U	0.4
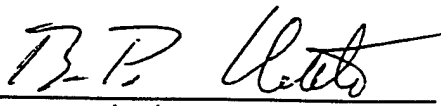
Surrogate Recovery   (1-Chloro-2-Fluoro-Benzene)   :   122%
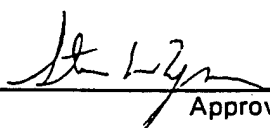
QUALIFIERS:
U = Compound analyzed for, but not detected.
B = Compound in blank and sample. Compare blank and sample date.
EDL = Evergreen's Estimated Detection Limit.

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Analyst

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Approved

MEB090894 Methanol Blank

Surrogate

Chloroform

Dichloromethane

1.5e4
1.4e4
1.3e4
1.2e4
1.1e4
1.0e4
9000
8000
7000
6000

10   20   30   40   50   60

Date Run: 09-08-94
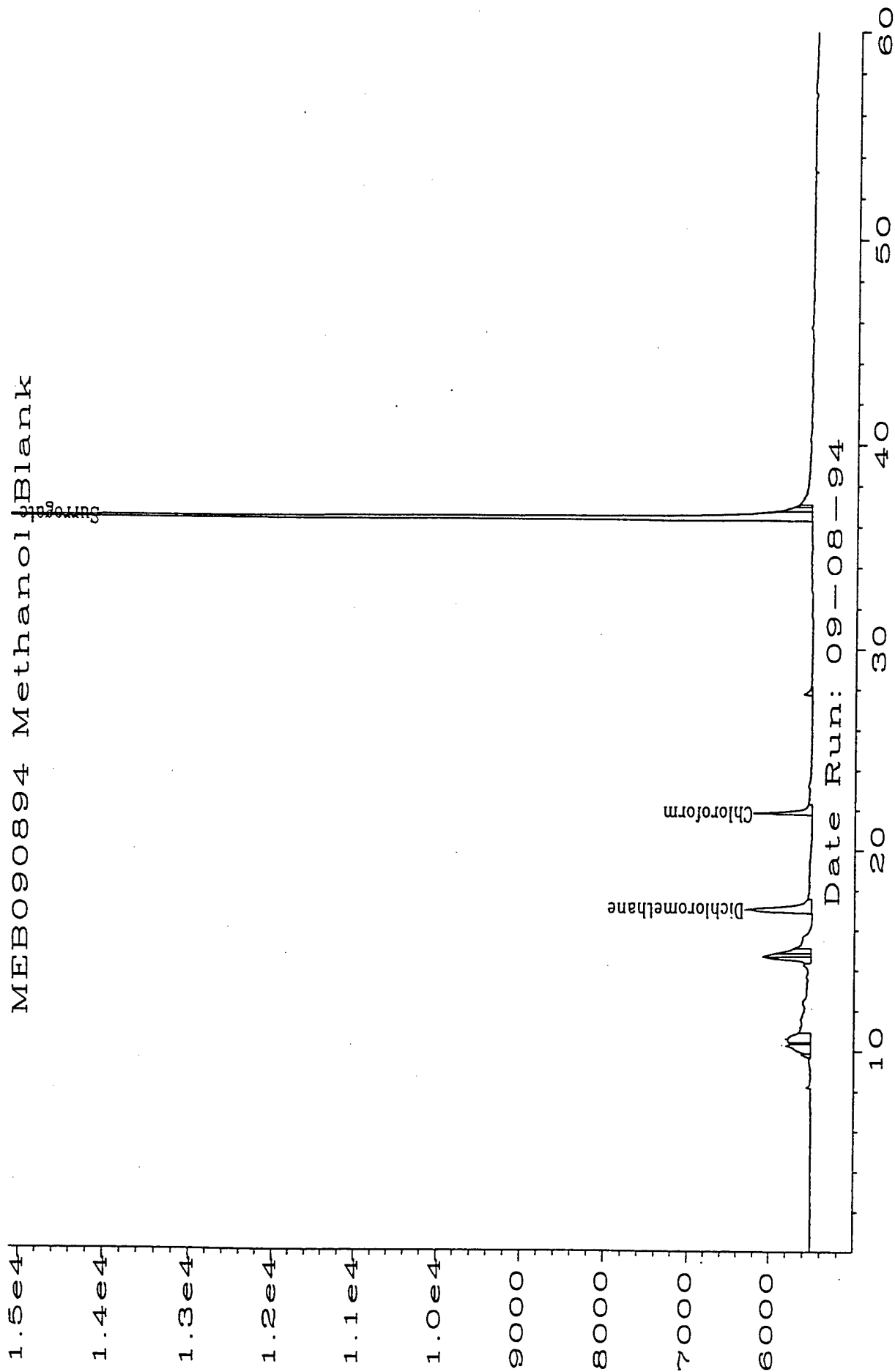
Sig. 2 in C:\HPCHEM\2\DATA\HALLO908\005R0101.D

EVERGREEN ANALYTICAL, INC.
4036 Youngfield, Wheat Ridge, CO 80033
(303) 425-6021

Method 8010 Matrix Spike/Matrix Spike Duplicate
Data Report

Client Sample #	: ESSB-2(21.75bgs)	Client Project #	: Battle Creek
Lab Sample #	: X93539	Lab Project #	: 94-3273
Date Sampled	: Not Specified	Matrix	: Soil
Date Received	: 8/29/94	Lab File #	: Hall0830008 47,48
Date Prepared	: 9/1/94	Method Blank	: MB083194
Date Analyzed	: 9/1/94	Dilution Factor	: 1.0

Compound	Spike Added (ug/L)	Sample Concentration (ug/Kg)	MS Concentration (ug/Kg)	MS % Rec.	QC Limits % Rec.
1,1-Dichloroethene	: 30	0	35	117%	59-172
Trichloroethene	: 30	0	29	98%	62-137
Chlorobenzene	: 30	0	32	106%	60-130
Surrogate Recovery (1-Chloro-2-Fluoro-Benzene)		:	102%		

Compound	Spike Added (ug/L)	MSD Concentration (ug/L)	MSD % Rec.	RPD*	QC Limits RPD*
1,1-Dichloroethene	: 30	33	110%	6	22
Trichloroethene	: 30	29	99%	1	24
Chlorobenzene	: 30	30	100%	6	21
Surrogate Recovery (1-Chloro-2-Fluoro-Benzene)		:	96%		

* = Relative Percent Difference
# = Values outside of QC limits.

Spike Recovery: 0 out of 6 outside limits.
RPD: 0 out of 3 outside limits.

Comments:

_____
Analyst

_____
Approved

X93539-MS DF=1 Client #E:SSB-2(21.75'bgs)

Date Run: 09-01-94

Sig. 2 in C:\HPCHEM\2\DATA\HALL0830\047R0101.D

X93539-MSD DF=1 Client #ESSB-2(21.75'bgs)

Date Run: 09-01-94

Sig. 2 in C:\HPCHEM\2\DATA\HALL0830\048R0101.D

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=================================================================================
                        External Standard Report
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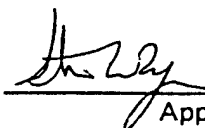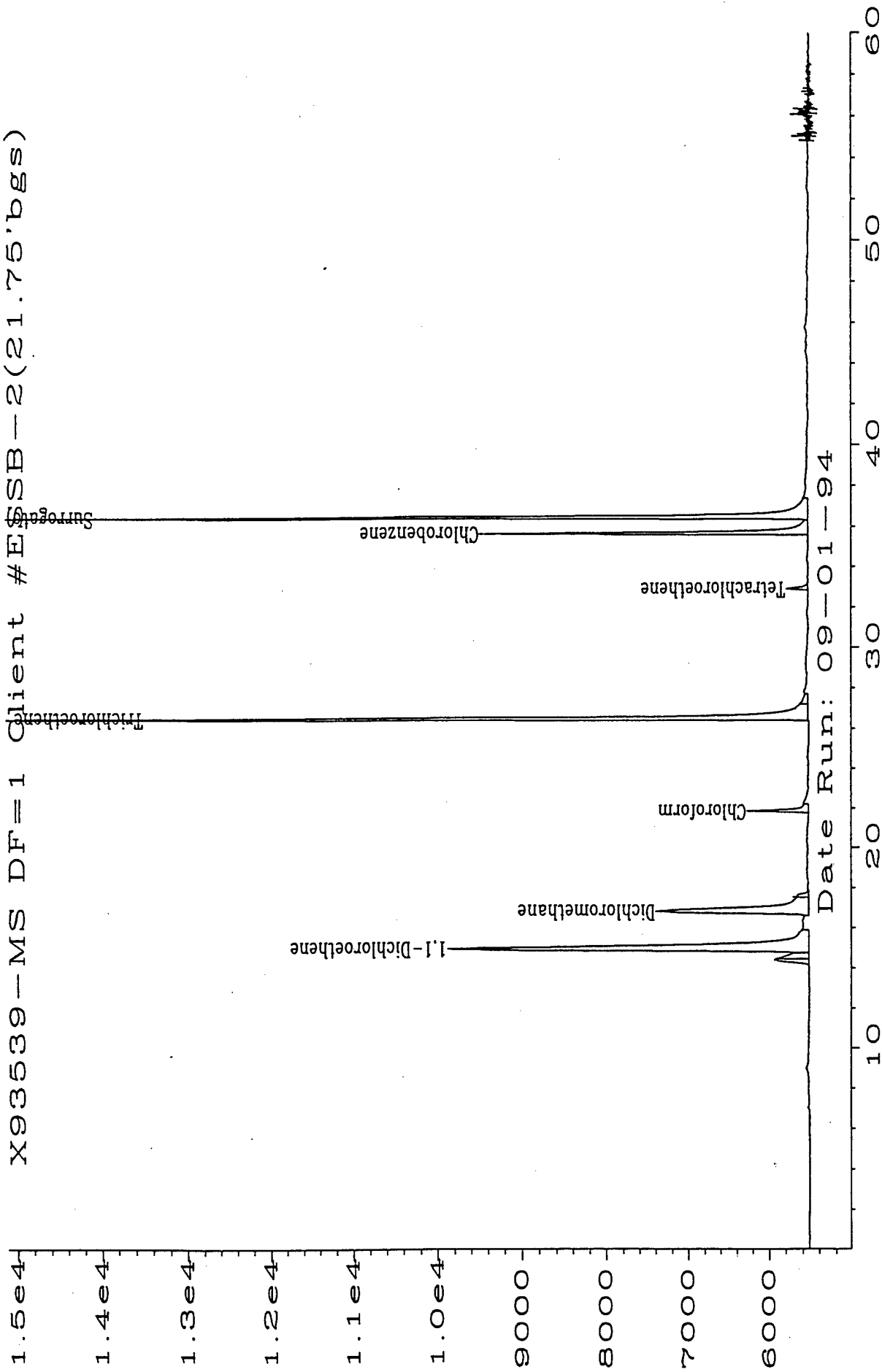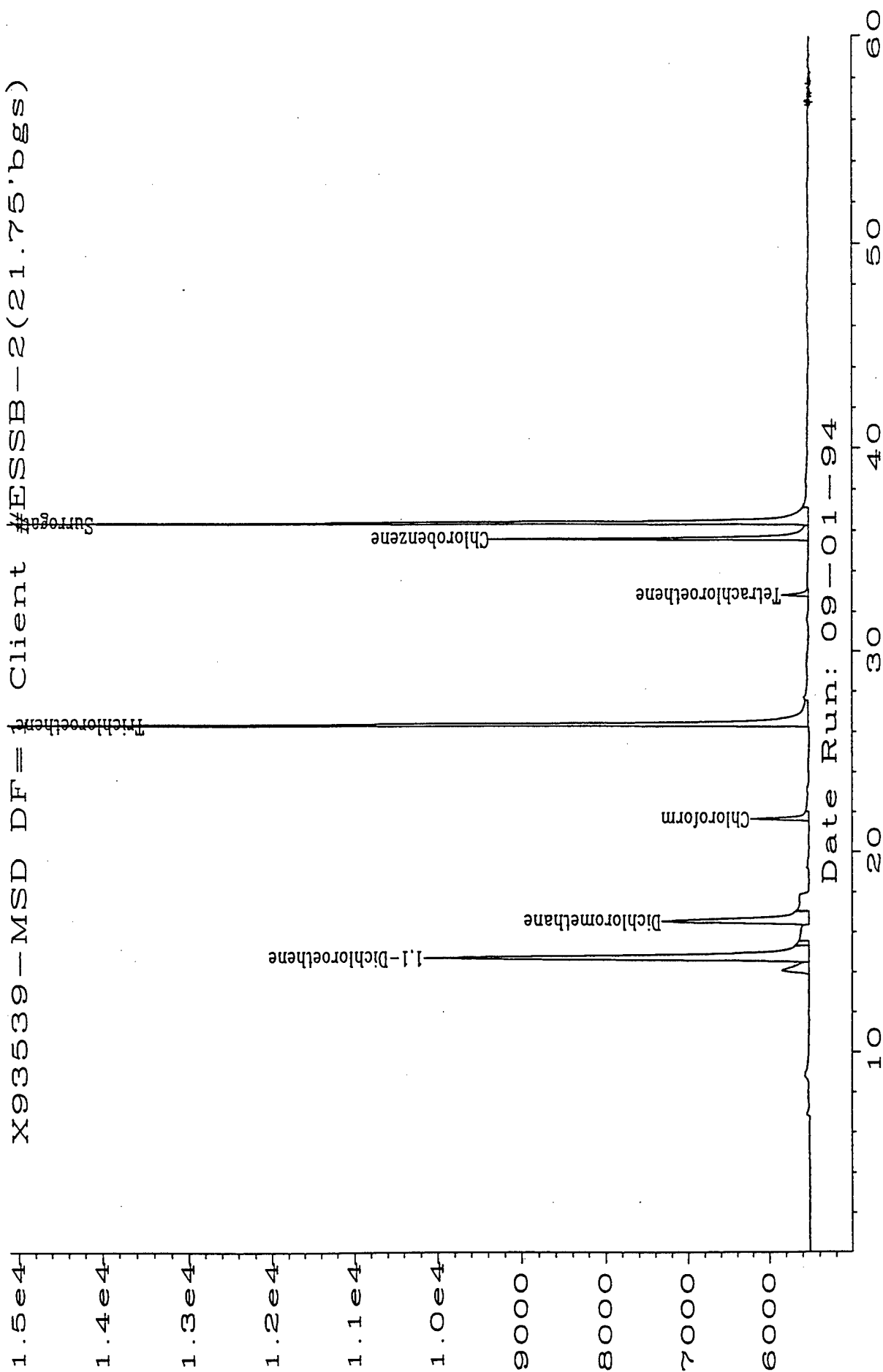
Data File Name   : C:\HPCHEM\2\DATA\HALL0830\049R0101.D
C·~ator   : Ben Lobato   *BL*   Page Number   : 1
i·~ument   : HALL1   Vial Number   : 49
S⬤⬤ Name   : Ref. Std.   *30ppb*   Injection Number : 1
Run·Time Bar Code: Sequence Line   : 1
Acquired on   : 01 Sep 94 06:35 PM   Instrument Method: HALLBASE.MTH
Report Created on : 07 Sep 94 03:07 PM   Analysis Method   : HALL0830.MTH
Last Recalib on   : 07 SEP 94 02:27 PM   Sample Amount   : 0
Multiplier   : 1   ISTD Amount   :

Sig. 2 in C:\HPCHEM\2\DATA\HALL0830\049R0101.D

Ret Time	Area	Type	Width	Ref#	ul/L	Name
6.832	29943	PH	0.288	1	37.789	Dichlorodifloromethane
8.006	28917	HH	0.223	1	40.585	Chloromethane
8.626	64311	HH	0.236	1	42.538	Vinyl Chloride
10.692	17887	MM	0.209	1	43.167	Bromomethane
11.051	69781	HH	0.280	1	33.315	Chloroethane
12.183	71554	MM	0.356	1	38.558	Trichlorofluoromethane
14.682	83832	HH	0.209	1	38.534	1,1-Dichloroethene
16.500	110843	HH	0.194	1	33.398	Dichloromethane
17.537	77528	HH	0.134	1	35.291	trans-1,2-Dichloroethene
19.022	80354	HH	0.130	1	35.036	1,1-Dichloroethane
21.626	106923	HH	0.115	1	32.877	Chloroform
22.971	88629	HH	0.135	1	32.056	1,1,1-Trichloroethane
23.811	95447	HH	0.128	1	34.685	Carbon Tetrachloride
24.248	86187	HH	0.116	1	36.334	1,2-Dichloroethane
?6.328	89688	HH	0.102	1	29.634	Trichloroethene
⬤862	76961	HH	0.124	1	26.737	1,2-Dichloropropane
⬤621	70205	HH	0.116	1	32.325	Bromodichloromethane
28.543	19161	HH	0.133	1	63.479	2-chloroethyl vinyl ether
29.375	66996	HH	0.112	1	33.602	cis-1,3-Dichloropropene
31.010	57405	HH	0.101	1	32.852	trans-1,3-Dichloropropene
31.565	83877	HH	0.100	1	32.196	1,1,2-Trichloroethane
32.754	98307	HH	0.104	1	36.441	Tetrachloroethene
33.376	53137	HH	0.109	1	35.224	Dibromochloromethane
35.553	33633	PH	0.110	1	34.040	Chlorobenzene
36.336	77396	HH	0.108	1-R	0.000	Surrogate
38.854	26676	BH	0.105	1	35.581	Bromoform
39.353	58594	HH	0.107	1	31.965	1,1,2,2-Tetrachloroethane
43.834	45816	PH	0.097	1	35.805	1,3-Dichlorobenzene
44.216	54065	HH	0.098	1	36.250	1,4-Dichlorobenzene
45.608	49800	HH	0.108	1	36.755	1,2-Dichlorobenzene

Time Reference Peak	Expected RT	Actual RT	Difference
25	36.320	36.336	0.016

User Modified

30 ppb REFERENCE

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cur·
9/14/94

APPENDIX C

MODEL INPUT AND RELATED CALCULATIONS

Model Grid with boundary Conditions
Michigan Air National Guard, Battle Creek, MI
722450.10
by J.Black

Columns 1–20, Rows 1–20. Border cells marked X (no-flow). Constant head cells with assigned head values shown below.

Row 2: (col 8) 886.2, (9) 888.3, (10) 888.5, (11) 889.6, (12) 888.7, (13) 889.65, (14) 889.8, (15) 889.75, (16) 889.75, (17) 889.75, (18) 889.75, (19) 889.75

Row 3: (col 6) 886.3, (7) 886.5

Row 4: (col 4) 889.3, (5) 890.5

Row 5: (col 3) 988.5

Row 6: (col 2) 888.5

Row 19: (col 2) 892, (3) 892, (4) 892, (5) 892.5, (6) 892.5, (7) 892.5, (8) 892.7, (9) 893.25, (10) 893.25, (11) 893.25, (12) 893.25, (13) 893.25, (14) 893, (15) 892.5, (16) 892.5, (17) 892.5, (18) 892, (19) 892, (20?) 894.7

X = No-flow cell

892 = Constant Head Cell, with assigned head value

Model Grid with Calibrated transmissivity array (ft²/sec)
Michigan Air National Guard, Battle Creek, MI
722 450 .10

$1 = 6.7 \times 10^{-3}$ ft²/sec
$2 = 5.0 \times 10^{-4}$ ft²/sec
$3 = 3.0 \times 10^{-3}$ ft²/sec
$4 = 3.0 \times 10^{-2}$ ft²/sec

Longitudinal Dispersivity Estimation
Michigan Air National Guard, Battle Creek, MI
722450.10
J. Black   12/8/94

The plume is relatively symmetrical and moving approximately parallel to the model grid, so a longitudinal moment may be calculated.

Based on figure 4.2 and the model grid, an estimate for the center of mass will be made by calculating the longitudinal moment of the plume (along column 10) about cell 10,14 which is the approximate location of the source area.

Row	Mass	Distance from 10,14 (feet)	Mass x Distance
13	110	90	9900
12	40	180	7200
11	25	270	6750
10	10	360	3600
9	5	450	2250
8	4	540	2160
	194		31860

The estimated Centroid is $\frac{31860}{194} = 164'$ (from the center of cell 10,14

164' is also the distance from the source to the centroid

Longitudinal dispersibity is commonly assumed to be $1/10$ the distance from the source to the plume centroid.

Therefore, the longitudinal dispersivity may be estimated as:
$$\frac{164'}{10} = 16 \text{ feet}$$

RMS Error Calculations for Calibrated Flow Model
Site 3, Battle Creek ANGB
bcwt21.dat

Point Number	Cell Location x,y	Measured Head Hm	Simulated Head Hs	Hm - Hs	$(Hm - Hs)^2$
ESMP-12	9,8	889.18	889.32	-0.14	0.02
MW-6	10,10	890.32	889.94	0.38	0.14
ESMP-6	12,11	890.77	890.88	-0.11	0.01
ESMP-5	11,12	891.27	891.29	-0.02	0.00
ESMP-7	10,13	891.57	891.74	-0.17	0.03
ESMP-3	11,13	891.69	891.75	-0.06	0.00
ESMP-2	10,14	891.98	892.09	-0.11	0.01
ESMP-1	11,14	892.11	892.05	0.06	0.00
MW-1	11,16	892.61	892.59	0.02	0.00

Sum of Squares of Remainders	0.22
Average of Squares of Remainders	0.02
RMS	0.16
RMS as a percentage of the head drop over the model domain	3.13

Simulated Head vs. Measured Head, Battle Creek Model

$y = 1.0102x - 9.0396$
$R^2 = 0.9759$

Simulated Head (feet)

Measured Head (feet)
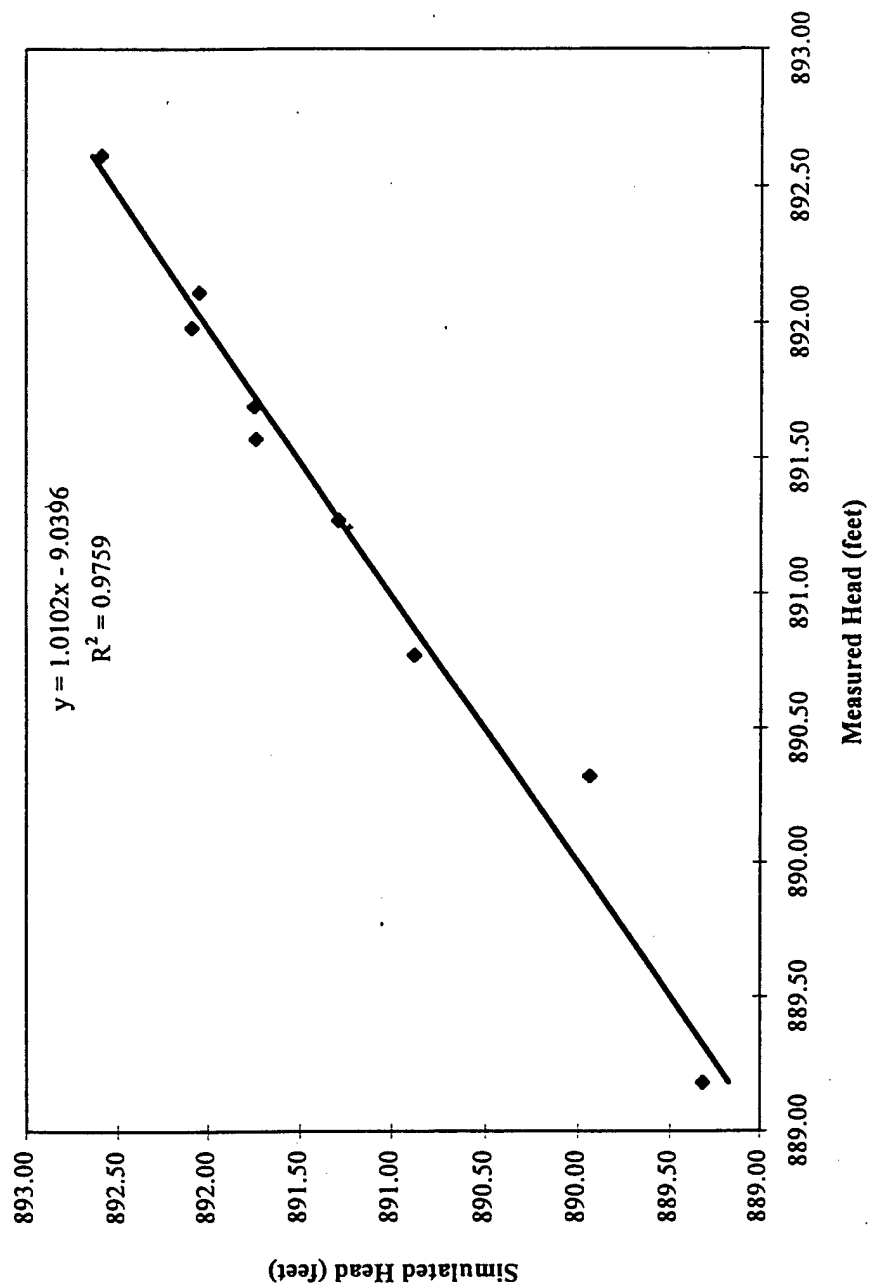
Battle Creek   722450.10   J Black

Calculation of residual BTEX in soil in capillary fringe at
   fire training area based on measured BTEX in soil sample
   from ESSB-6 at 27-27.5 feet bgs

1) Volume of soil beneath fire training area in capillary fringe
     Assumptions:
         h = capillary fringe + water table = 3 ft   (0.91 m)
         r = radius of fire training area = 35 ft.   (10.67 m)
         ϕ = porosity = 30%
         vol. of soil = $\pi r^2 h (1-\phi)$
                     = 8081.5 ft^3 (228.57 m^3)

2) Mass of soil: assume sand w/ density of 2.65 g/cm^3 = 2.65 × 10^3 kg/m^3
       (228.87 m3)(2.65×10^3 kg/m^3) = 606,505 kg

3) Mass of residual BTEX
       (4982.5 μg/kg)(606,505 kg) = 3.02 × 10^9 μg = 3.02 kg

4) Volume of water in capillary fringe
       $\pi r^2 h (0.3)$ = 3463.5 ft^3 = 98.1 m^3

5) Mass of dissolved BTEX with instantaneous flushing & dissolution
     of residual into groundwater
       $\dfrac{\text{Mass residual BTEX}}{\text{Vol. of water}}$ = $\dfrac{3.02 kg}{98.1 m^3}$ = 3.0785 $\dfrac{kg}{m^3}$ = 30,785 μg/ℓ

6) Present Maximum measured dissolved BTEX at VW = 3552 μg/ℓ

    Leaching potential = $\dfrac{\text{Max. mass dissolved}}{\text{present dissolved}}$ = $\dfrac{30,785}{3552}$ = 8.7

APPENDIX D

MODEL INPUT AND OUTPUT FILES

APPENDIX E

REMEDIAL ALTERNAITVE COST CALCULATIONS

Battle Creek Alternative 1 Cost Estimate

Capital Costs

Design/Construct 4-2" PVC POC wells and 3-2" PVC LTM wells

Design/Plan	50 hrs	$70/hr	$3,500
Drilling	250 ft	$60/ft	$15,000
Installation Labor	100 hrs	$65/hr	$6,500
Other Costs (per diem, travel, etc.)			$2,000
			$27,000

Operations, Maintenance, Monitoring - Annual Costs

Operate and maintain existing bioventing unit (4 years)

4 hrs/week x 52 weeks x $50/hr	$10,400
Supplies and power/year	$5,000
	$15,400

Monitor 9 groundwater wells annually (12 years)

80 hrs/event x $50/hr	$4,000
8020 analysis 10 @ $100 ea	$1,000
Supplies/misc	$1,000
	$6,000

Institutional Controls/Public Management (12 years)

$5000/yr	$5,000

Project Management/Regulatory Report (12 years)

$6000/yr	$6,000

Summary of Capital and Present Worth Costs for Alternative 1

Capital Costs
Design/Construct 4-2" PVC POC wells and 3-2" PVC LTM wells

    P/F i=5% n=1   Present Worth Cost $27,000

Operations, Maintenance, and Monitoring Costs

Operate and maintain existing bioventing unit (4 years)

Cost per Event		$15,400
P/A i=5%, n=1.0	1994	$14,666.67
P/A i=5%, n=2.0	1995	$13,968.25
P/A i=5%, n=3.0	1996	$13,303.10
P/A i=5%, n=4.0	1997	$12,669.62
	Total Present Worth Cost	$54,608

Annual Monitoring of 9 wells, 1994-2005 (12 years)

Cost per Event		$6,000
P/A i=5%, n=1.0	1994	$5,714.29
P/A i=5%, n=2.0	1995	$5,442.18
P/A i=5%, n=3.0	1996	$5,183.03
P/A i=5%, n=4.0	1997	$4,936.21
P/A i=5%, n=5.0	1998	$4,701.16
P/A i=5%, n=6.0	1999	$4,477.29
P/A i=5%, n=7.0	2000	$4,264.09
P/A i=5%, n=8.0	2001	$4,061.04
P/A i=5%, n=9.0	2002	$3,867.65
P/A i=5%, n=10.0	2003	$3,683.48
P/A i=5%, n=11.0	2004	$3,508.08
P/A i=5%, n=12.0	2005	$3,341.02
	Total Present Worth Cost	$53,180

Institutional Controls/Public Management (12 years)

Annual Cost	$5,000	
P/A i=5% n=12	PWF = 8.863251636	
	Present Worth Cost	$44,316

Project Management/Regulatory Report (12 years)

Annual Cost	$6,000	
P/A i=5% n=12	PWF = 8.863251636	
	Present Worth Cost	$53,180

Total Capital and Present Worth Costs of LTM Program	$232,283

Battle Creek Alternative 2 Cost Estimate

Capital Costs

Design/Construct 4-2" PVC POC wells and 3-2" PVC LTM wells

Design/Plan	50 hrs	$70/hr	$3,500
Drilling	250 ft	$60/ft	$15,000
Installation Labor	100 hrs	$65/hr	$6,500
Other Costs (per diem, travel, etc.)			$2,000
			$27,000

Maintenance and Monitoring - Annual Costs

Monitor 9 groundwater wells annually (20 years)

80 hrs/event x $50/hr	$4,000
8020 analysis 10 @ $100 ea	$1,000
Supplies/misc	$1,000
	$6,000

Institutional Controls/Public Management (20 years)

$5000/yr	$5,000

Project Management/Regulatory Report (20 years)

$6000/yr	$6,000

Summary of Capital and Present Worth Costs for Alternative 2

Capital Costs
Design/Construct 4-2" PVC POC wells and 3-2" PVC LTM wells
P/F i=5% n=1   Present Worth Cost $27,000

Maintenance and Monitoring Costs

Annual Monitoring of 9 wells, 1994-2013 (20 years)

		Cost per Event	$6,000
P/A i=5%, n=1.0	1994	$5,714.29	
P/A i=5%, n=2.0	1995	$5,442.18	
P/A i=5%, n=3.0	1996	$5,183.03	
P/A i=5%, n=4.0	1997	$4,936.21	
P/A i=5%, n=5.0	1998	$4,701.16	
P/A i=5%, n=6.0	1999	$4,477.29	
P/A i=5%, n=7.0	2000	$4,264.09	
P/A i=5%, n=8.0	2001	$4,061.04	
P/A i=5%, n=9.0	2002	$3,867.65	
P/A i=5%, n=10.0	2003	$3,683.48	
P/A i=5%, n=11.0	2004	$3,508.08	
P/A i=5%, n=12.0	2005	$3,341.02	
P/A i=5%, n=13.0	2006	$3,181.93	
P/A i=5%, n=14.0	2007	$3,030.41	
P/A i=5%, n=15.0	2008	$2,886.10	
P/A i=5%, n=16.0	2009	$2,748.67	
P/A i=5%, n=17.0	2010	$2,617.78	
P/A i=5%, n=18.0	2011	$2,493.12	
P/A i=5%, n=19.0	2012	$2,374.40	
P/A i=5%, n=20.0	2013	$2,261.34	

Total Present Worth Cost $74,773

Institutional Controls/Public Management (20 years)

Annual Cost $5,000
P/A i=5% n=20   PWF = 12.46221034

Present Worth Cost $62,311

Project Management/Regulatory Report (20 years)

Annual Cost $6,000
P/A i=5% n=20   PWF = 12.46221034

Present Worth Cost $74,773

Total Capital and Present Worth Costs of LTM Program	$238,858

APPENDIX F

RESPONSES TO COMMENTS

PARSONS

Parsons Engineering Science, Inc. • **A Unit of Parsons Infrastructure & Technology Group Inc.**
1700 Broadway, Suite 900 • Denver, Colorado 80290 • (303) 831-8100 • Fax (303) 831-8208 • www.parsons.com

18 June, 1999

Mr. Jerry Hansen
AFCEE/ERT
3207 North Road, Building 532
Brooks AFB, TX 78235

Subject: Responses to Comments on the Draft Treatability Study in Support of Intrinsic
Remediation for the Fire Training Area (Site 3), Michigan Air National Guard,
Battle Creek, Michigan (Contract F41624-92-D-8036)

Dear Mr. Hansen:

This letter provides responses to comments received on the Draft Treatability Study
(TS) in Support of Intrinsic Remediation for the Fire Training Area (Site 3), Michigan
Air National Guard, Battle Creek, Michigan. The draft TS was prepared by Parsons
Engineering Science, Inc. (Parsons ES) for the Air Force Center for Environmental
Excellence, Technology Transfer Division (AFCEE/ERT) and the Michigan Air National
Guard. The intent of the TS was to determine the role of natural attenuation in
remediating fuel contamination in groundwater at the Fire Training Area (Site 3). The
draft TS was submitted to AFCEE and the Michigan Air National Guard in March 1995.
AFCEE's comments on the draft TS, dated April 1995, were prepared by Chung Yen and
an unspecified author. In addition, comments dated 19 July 1995 were received from
Booz•Allen & Hamilton (Daniel Kraft). The Michigan Air National Guard did not
provide comments. Responses to these comments were prepared by Parsons ES and are
presented herein.

Comments to Parsons ES from AFCEE (Chung Yen)

Correspondence dated 18 April 1995

Comment #1:   *The figures and text pages should be stamped "Draft".*

Response: Once these comments are addressed, the TS will be delivered in final
format. Therefore, this comment will not apply to the final version of this
report.

Comment #2: *Executive Summary, Pg ES-1, lines 7-9: Add "the" before "dissolved". Change "in" before "the gaseous phase..." to "in".*

Response: This sentence now reads, "Contamination is present as residual light nonaqueous-phase liquid (LNAPL) sorbed to the aquifer matrix, as dissolved constituents in groundwater, and as vapor in the unsaturated zone."

Comment #3: *Section 4.3.1.1, Para 2, Sentence 3: this is a dangling sentence.*

Response: The sentence now reads, "The highest BTEX concentration of 3,552 µg/L was detected at bioventing vent well VW-1."

Comment #4: *Section 4.3.1.1: Why were the three isomers of TMB analyzed? Does Michigan's TMB in groundwater standards exist? If so, how do they compare to current TMB groundwater data?*

Response: Trimethylbenzenes (TMBs) are water-soluble fuel constituents considered to be recalcitrant to biological degradation under anaerobic conditions. Therefore, they are commonly used as tracer compounds to calculate first-order BTEX degradation rates under anaerobic conditions. Biodegradation was simulated in the numerical model using a reaeration coefficient, which simulates replenishment of oxygen into groundwater. Therefore, the TMB data were not used to calculate a first-order rate. A Michigan standard for TMB does not exist.

Comment #5: *Figure 4.2: BTEX isopleth from prior data on a separate or same figure will be helpful to show bioattenuation activities in the past before this study. Historical benzene isopleth superimposed on current benzene isopleth can also show bioactivities.*

Response: Data collected in 1988, 1989 and 1991 are not sufficient for the construction of isopleths for groundwater contaminants at Site 3. However, groundwater contaminant data for prior years is presented on Figure 2.8 in the Work Plan (Parsons, 1994), and in tabular in an update Addendum to the TS (Appendix to the final TS [pending]).

Comment #6: *Section 6, Comparative Analysis of Remedial Alternatives:*

Comment 6(1) *Costing worksheets and present worth calculations are missing from this report. They should be included as cost estimate basis. The sources of cost information in the worksheets and calculations should also be described and referenced.*

Response: Costing worksheets and present worth calculations will be included as an appendix to the final report (Appendix E). The text in Section 6 will be altered to reference Appendix E.

Comment 6(2) *For alternative 1, the number and depth/size of bioventing wells are not specified. Also need to specify that the POC well are cost out as monitoring wells.*

Response: The text will be altered to incorporate the depth/size of the proposed wells. In addition, the text now specifies that POC wells are costed the same as LTM wells.

Comment 6(3) *Likewise for alternative 2, the text need to specify that the POC well are cost out as monitoring wells.*

Response: The text will be altered to specify that POC wells are costed as LTM wells.

Comment #7: *Table 6.5, Summary of Alternatives Evaluation, Pg 6-25: the text under "Effectiveness" column for alternative 1 states that "MCL for benzene not likely to be exceeded at the POC". Is this also probable for toluene, ethylbenzene, and xylene concentrations at the POC wells based on the modeling results? This should be discussed and explicitly stated.*

Response: The model for Alternative 1 indicates that the BTEX plume will not migrate more than 720 feet from the source area (Section 5.7). The recommended POC wells are located approximately 900 feet from the source area (Figure 7.1). Therefore, it is unlikely that any of the BTEX compounds will exceed MCLs at the POC. The text in Table 6.5 and Section 6.4.4.1 will be revised to state that none of the BTEX compounds are likely to exceed MCLs at the POC under Alternative 1.

Comments by AFCEE/ERT (unspecified author)

Memo dated 18 April 1995

Comments #1: *(Para 1.2.1, page 1-6) Provide a summary of the data gathered during the 1988, 1989, and 1991 investigations.*

Response: Data collected prior to the TS was summarized in the TS work plan (Parsons ES, 1994) and in an update addendum prepared as an attachment to the final TS (pending). The text has been changed to read, "Data gathered during the 1988, 1989, and 1991 investigations are presented in the Work Plan (Parsons ES, 1994) and in the TS Addendum (Appendix F)."

Comment #2: *(Para 4.2.1.2, page 4-6) Indicate that the weathering of BTEX is attributing to bioventing.*

Response: The last sentence in Section 4.2.1.2 will be replaced with the following paragraph:

"The lack of correlation between the distribution of TPH and BTEX concentrations may result from bioventing or natural weathering processes. Compared to heavier compounds in a fuel mixture, BTEX compounds are more volatile and soluble, less retarded, and more susceptible to natural biodegradation. As a result, the BTEX concentrations in soil would be expected to decrease more rapidly relative to other heavier constituents in a fuel mixture (i.e., more rapidly than overall TPH). The preferential removal of BTEX during bioventing is described in Section 5.6.2."

Comment #3: *(Para 4.3.1, page 4-7, 2d sentence) This sentence sounds like nothing is degrading. Indicate contaminant levels found in early investigation and compare to the 94 data.*

Response: Data collected during field investigations conducted in 1988, 1989, and 1991 is summarized in the Work Plan (Parsons ES, 1994). An analysis of the temporal and spatial trends relating to previous data is presented in the TS Addendum (pending attachment to the final TS). The referenced sentence will be changed to read: "Groundwater samples collected in August 1994 by Parsons ES and RSKERL personnel confirmed the presence of petroleum hydrocarbons."

Comment #4: *(Para 4.3.1.1, page 4-7, 2d para, 3d sentence) "bioventing well at. " Indicate the well location.*

Response: The text has been altered to read, "The highest BTEX concentration of 3,552 µg/L was detected at bioventing vent well VW-1."

Comment #5: *(Page 4-11, figure 4.2) Add a BTEX isopleth for the older groundwater data.*

Response: Data collected in 1988, 1989 and 1991 are not sufficient for the construction of isopleths for ground water contaminants at Site 3. However, groundwater contaminant data for prior years is presented on Figure 2.8 in the Work Plan (Parsons, 1994), and in tabular form in an update Addendum to the TS (Appendix to the final TS [pending]).

Comment #6: *(Para 5.4, page 5-7) Consider using the historic data for model calibration.*

Response: Historic data was considered in the calibration of the model. However, the 1994 data provided the most extensive, complete, and up-to-date source of information pertaining to groundwater quality at Site 3. Therefore, the model was calibrated to 1994 data.

Comment #7: *(Page 5-15, figure 5.4) This calibrated BTEX plume does not compare well to the 1994 BTEX plume shown by figure 4.2.*

Response: The modeled BTEX plume was calibrated to the existing plume in terms of migration distance and source area concentrations. As stated in Section 5.4.2.1: "The highest measured BTEX concentration (3,552 μg/L at the vent well) is simulated in the calibrated model at 3,105 μg/L. Several of the contour intervals plotted from the calibrated model (10-, 50-, and 1,000-μg/L) delineate areas more extensive than indicated by the observed concentrations. This is an unavoidable result of the injection concentrations necessary to simulate the extent of the observed BTEX plume and illustrates one of the limitations of Bioplume II to accurately characterize actual physical site conditions. In particular, the model allows only the application of a constant reaeration coefficient over the extent of the modeled area. Simulations with lower BTEX input concentrations resulted in a more restricted plume extent. Similarly, higher reaeration coefficients resulted in restriction of plume migration. The application of localized variations in the reaeration coefficient would allow more detailed reproduction of the extent of the plume while decreasing the concentrations in the interior of the plume. The computed plume is useful, however, in that it conservatively approximates the observed distribution of BTEX. Although resulting concentrations exceed measured concentrations, it will provide a more conservative estimate of plume migration".

Comment #8: *(Para 5.6.1, page 5-24, 2d para on) Consider adding a figure to illustrate this discussion.*

Response: Model descriptions for one and fives years are presented in the narrative for Section 5.6.1. Because recent data (1998) is presented in an update Addendum to the TS (pending), a figure will be added to show the predicted model simulation at five years (1999) for comparison.

Comments to AFCEE (Lt. Col. Ross Miller) from Booz•Allen & Hamilton Inc. (Daniel Kraft)

<u>Letter dated 19 July 1995</u>

Comment #1: *The grammar of the last sentence in the first paragraph should be corrected. (Pg. 5-18, S 5.5)*

Response: The text has been fixed accordingly.

Comment #2: *Should the acronym for the model run which incorporates source removal via bioventing be "BVSR"? It is unclear what the letter "C" in the acronym "BCSR," used throughout the remainder of the text. (Pg. 5-27, S 5.6.2)*

Response: The acronym "BCSR" was initially selected for "Battle Creek Source Reduction", indicating source removal via bioventing, and is used throughout the report and model files. Changing the acronym at this point would cause confusion if Bioplume model results in Appendix D are accessed. To minimize confusion, the acronym "BCSR" will be added to the acronym list as "Battle Creek Source Reduction (model simulation for source removal via bioventing)."

Comment #3: *Provide an explanation for the predicted increase in the dissolved-phase plume BTEX concentrations after 3 years. (Pg. 5-29, S 5.6.2)*

Response: The reported 3-year concentration is not correct. The actual simulated maximum BTEX concentration after 3 years is approximately 1,000 µg/L. The text will be corrected.

Comment #4: *Based on the vertical distribution of dissolved-phase BTEX, as depicted on Figure 4.3, the use of 10-foot screens with eight feet of screen below the water table should be reconsidered for the point of compliance (POC) wells. Nested screen intervals should be considered to monitor possible downward migration of the dissolved-phase hydrocarbon plume and prevent the sample dilution which could occur with longer screen intervals. (Pg. 7-2, S 7.2)*

Response: Parsons ES agrees, and will recommend that selected POC and LTM wells located along the plume axis be nested to monitor possible downward migration of the dissolved-phase hydrocarbon plume. In addition, 5-foot screens in lower portions of the aquifer will be recommended to prevent sample dilution. The text in Section 7 has been altered to reflect this change.

If you have any questions or require additional information, please call me at (303) 831-8100.

Sincerely,

PARSONS ENGINEERING SCIENCE, INC.

Bruce M. Henry, P.G.
Project Manager

cc: Mr. John Hicks, Parsons ES
        File 722450.16000

APPENDIX G

**FINAL REMEDIATION BY NATURAL ATTENUATION
TREATABILITY STUDY ADDENDUM**

FINAL
ADDENDUM TO THE TREATABILITY STUDY
IN SUPPORT OF INTRINSIC REMEDIATION

for

FIRE TRAINING AREA (SITE 3)
MICHIGAN AIR NATIONAL GUARD
W. K. KELLOGG MEMORIAL AIRPORT
BATTLE CREEK, MICHIGAN

September 1999

Prepared for:

AIR FORCE CENTER FOR ENVIRONMENTAL EXCELLENCE
BROOKS AIR FORCE BASE
SAN ANTONIO, TEXAS

AND

110th TACTICAL FIGHTER GROUP
MICHIGAN AIR NATIONAL GUARD
BATTLE CREEK, MICHIGAN

Prepared by:

Parsons Engineering Science, Inc.
1700 Broadway, Suite 900
Denver, Colorado 80290

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LIST OF ACRONYMS AND ABBREVIATIONS

1,1-DCE	1,1-dichloroethene
μg/L	micrograms per liter
AFCEE	Air Force Center for Environmental Excellence
amsl	above mean sea level
BTEX	benzene, toluene, ethylbenzene, and xylenes
CAHs	chlorinated aliphatic hydrocarbons
cis-1,2-DCE	*cis*-1,2-dichloroethene
DO	dissolved oxygen
ES	Engineering Science, Inc.
Fe^{2+}	ferrous iron
ft/ft	foot per foot
LTM	long-term monitoring
MCL	maximum contaminant level
mg/L	milligrams per liter
MTBE	methyl tert-butyl ether
mV	millivolts
N	nitrogen
NH_3	ammonia
NRMRL	National Risk Management Research Laboratory
ORP	oxidation-reduction potential
Parsons ES	Parsons Engineering Science, Inc.
PCE	tetrachloroethene
TCE	trichloroethene
TMBs	trimethylbenzenes
trans-1,2-DCE	*trans*-1,2-dichloroethene
TS	Treatability Study
USEPA	US Environmental Protection Agency
VC	vinyl chloride
VOCs	volatile organic compounds

1.0 INTRODUCTION

This document was prepared for the Air Force Center for Environmental Excellence (AFCEE) by Parsons Engineering Science, Inc. (Parsons ES) as an addendum to the Draft Treatability Study (TS) in Support of Intrinsic Remediation for the Fire Training Area (Site 3), Michigan Air National Guard at W.K. Kellogg Memorial Airport, Battle Creek, Michigan, (Parsons ES, 1995 [final pending]) under Air Force contract number F41624-92-D-8036. The Draft TS was completed to evaluate the use of intrinsic remediation (natural attenuation) with long-term monitoring (LTM) for remediation of groundwater contaminated with fuel hydrocarbons at Site 3.

This addendum documents the effectiveness of natural attenuation at the site by summarizing results of two groundwater sampling events that were conducted by researchers from the United States Environmental Protection Agency (USEPA) National Risk Management Research Laboratory (NRMRL) Subsurface Protection and Remediation Division in June 1995 and April 1998. Groundwater was originally sampled in August 1994 for the TS. The focus of this addendum is to evaluate changes in concentrations of dissolved benzene, toluene, ethylbenzene, and xylenes (BTEX); BTEX plume extent; and natural attenuation mechanisms through time. Concentrations of dissolved chlorinated aliphatic hydrocarbons (CAHs), or chlorinated solvents, also are evaluated. Results, calculations, and predictions presented in the TS are used as the basis for comparison. Analytical data for the June 1995 and April 1998 sampling events are presented in Attachment A.

The Michigan Air National Guard facility (hereafter referred to as the Base) is located in the northwestern portion of the W.K. Kellogg Regional Airport in Battle Creek, Michigan. Site 3 is located in the western section of the Base and is approximately 500 feet north of the southeast-northwest runway. Groundwater contamination at Site 3 is suspected to have originated from fire training exercises conducted from approximately 1977 to 1986. A total of approximately 54,000 to 74,000 gallons of a mixture of waste JP-4 jet fuel, waste oils, waste hydraulic fluid, and spent cleaning solvents were reportedly burned during fire training exercises (Engineering Science, Inc. [ES], 1993).

A bioventing system has been in operation since 1992 at Site 3 (Figure 1) to remove source area contaminants. One bioventing well, located in the central part of the fire-training pit, was installed to expedite the biodegradation of BTEX constituents in the vadose zone. Additional site information, including site background, geology, and hydrogeology, is available in the Draft TS (Parsons ES, 1995).

2.0 MONITORING RESULTS

Since the August 1994 round of groundwater sampling performed for the TS (Parsons ES, 1995), researchers from the USEPA NRMRL have collected two rounds of update samples (June 1995 and April 1998) at Site 3. In June 1995, seven monitoring wells/points were evaluated at Site 3: ESMP-3D, ESMP-3DD, ESMP-3S, ESMP-4S, ESMP-4D, BC3-MW2, and BC3-MW4. However, three of the seven monitoring wells/points evaluated (ESMP-3S, ESMP-4S, ESMP-4D) were dry; therefore, no samples were collected at these locations. In April 1998 seven wells were evaluated at Site 3: ESMP-2S, ESMP-2D, ESMP-2DD,

- 1 -

FUEL
STORAGE
TANKS

ESMP-12S
ESMP-12D

BC3-MW6

ESMP-11S
ESMP-11D

ESMP-6S
ESMP-6D

ESMP-3S

ESMP-3D

ESMP-3DD

BASE SUPPLY
STORAGE

ESMP-5S

ESMP-5D

6940   6941

BC3-MW5

ESMP-7S

ESMP-4S

ESMP-7D

ESMP-4D

BC3-MW4

MOBILITY STORAGE
6909

ESMP-10S

BC3-MW3

ESMP-10D

ESMP-9S

BC3-MW2

FUEL PUMP
STATION
6907

ESMP-13S

VW-1

ESMP-1S

ESMP-2S

ESMP-1D

ESMP-2D

ESMP-2DD

BC3-MW1

ESMP-8D

ESMP-8S

LEGEND

ESMP-2S

◖ Groundwater Monitoring Well/Point

◆ Bioventing Well (VW-1)

○ Fire Training Area

N

0   75   150

Feet

FILE: ...\AESIREMEDIBIOPLUME\45010\UPDATE\MAP_INFO\Sitemap.WOR   DAT...9

FIGURE 1

SITE MAP

Site 3 (Fire Training Area)
Intrinsic Remediation TS Addendum
Michigan Air National Guard, W.K. Kellogg Airport
Battle Creek, Michigan

**PARSONS
ENGINEERING SCIENCE, INC.**

ESMP-4S, ESMP-4D, ESMP-3S, and BC3-MW4. Groundwater samples were collected from all seven monitoring wells/points. Groundwater monitoring locations at Site 3 are presented on Figure 1.

Samples collected in June 1995 and April 1998 were analyzed in the field for temperature, pH, conductivity, dissolved oxygen (DO), oxidation reduction potential (ORP), alkalinity, hydrogen sulfide, carbon dioxide, manganese, and ferrous iron. Additionally, samples were analyzed at the USEPA NRMRL in Ada, Oklahoma, for BTEX, trimethylbenzenes (TMBs), chlorinated volatile organic compounds (VOCs), sulfate, chloride, nitrate and nitrite as nitrogen (N), methane, ethene, ethane, and ammonia (NH_3). Methyl *tert*-butyl ether (MTBE) also was analyzed for in 1998, but was not detected. Analytical methods for April 1998 are summarized in Table 1.

2.1 Site Hydrogeology

Prior to purging and collecting samples from each monitoring location, depth to groundwater was measured to the nearest 0.1 foot in both June 1995 and April 1998. Groundwater elevation data and monitoring well/point completion information are summarized in Table 2. Figure 2 presents groundwater elevation contours for August 1994, June 1995, and April 1998. Groundwater elevations were measured in only two of the seven monitoring locations evaluated in June 1995 (BC3-MW2 and BC3-MW4). Monitoring points ESMP-3S, ESMP-4S and ESMP-4D were dry, and depth to groundwater was not measured in monitoring points ESMP-3D and ESMP-3DD.

Groundwater elevations measured in June 1995 were found to be 0.4 feet below the August 1994 groundwater elevations. Assuming similar trends, groundwater elevations of approximately 891.1 and 890.8 feet above mean sea level (amsl) would be expected in monitoring points ESMP-4S and ESMP-4D, respectively, during the June 1995 sampling event. The elevation of the screened intervals of ESMP-4S and ESMP-4D are 890.39-887.11 feet amsl and 887.21-873.93 feet amsl, respectively. The dry conditions at monitoring points ESMP-4S and ESMP-4D in June 1995 indicate that the groundwater elevations at these locations were lower than the bottom of the screen. Considering the measured groundwater elevations at monitoring wells BC3-MW2 and BC3-MW4 in June 1995, and the proximity of these wells to ESMP-4S and ESMP-4D, it is possible that either ESMP-4S and ESMP-4D were not functioning properly or that the water level measuring instrument used in June 1995 had malfunctioned. It is unclear why these monitoring points were dry during the June 1995 sampling event.

In April 1998, groundwater elevations were measured at six monitoring wells/points: ESMP-2S, ESMP-2D, ESMP-2DD, ESMP-4S, ESMP-4D, and BC3-MW4. Figure 2 presents groundwater elevations for April 1998 compared to data from August 1994 and June 1995. Groundwater elevations in April 1998 are slightly lower than measured in August 1994. Monitoring wells/points BC3-MW4, ESMP-4S, and ESMP-4D are the only sampling locations at which groundwater elevation data were collected during all three sampling events. While groundwater was not encountered during the June 1995 sampling round at monitoring points ESMP-4S and ESMP-4D, data collected in April 1998 indicates groundwater elevations similar to August 1994 elevations. The groundwater elevation

TABLE 1
SUMMARY OF GROUNDWATER ANALYTICAL METHODS
APRIL 1998
Site 3 (Fire Training Area)
Intrinsic Remediation TS Addendum
Michigan Air National Guard W.K. Kellogg Airport
Battle Creek, Michigan

Analyte	Method	Field (F) or Fixed-Base Laboratory (L)
Reduction/Oxidation Potential	Direct reading meter	F
Dissolved Oxygen	Direct reading meter	F
pH	Direct reading meter	F
Conductivity	Direct reading meter	F
Temperature	Direct reading meter	F
Manganese	Colorimetric, HACH Method 8034	F
Ferrous Iron (Fe^{2+})	Colorimetric, HACH Method 8146	F
Hydrogen Sulfide	HACH HS-C	F
Carbon Dioxide	Titrimetric, HACH Method 1436-01	F
Alkalinity (as $CaCO_3$)	Titrimetric, HACH Method 8221	F
Ammonia	Lachat FIA 10-107-06-1-A	L
Nitrite & Nitrate	Lachat FIA 10-107-04-2-A	L
Methane, Ethane, and Ethene	RSKSOP-194, -175[a]	L
Sulfate and Chloride	Waters Capillary Electrophoresis Method N-601	L
Chlorinated VOCs	RSKSOP-148	L
BTEX, TMBs, and MTBE[b]	RSKSOP-122	L

[a] RSKSOP = Robert S. Kerr Laboratory (now known as NRMRL) standard operating procedure.

[b] BTEX = benzene, toluene, ethylbenzene and xylenes; TMBs = trimethylbenzenes;
MTBE = methyl tert-butyl ether.

TABLE 2
WELL CONSTRUCTION INFORMATION AND WATER LEVEL DATA
Site 3 (Fire Training Area)
Intrinsic Remediation TS Addendum
Michigan Air National Guard W.K. Kellogg Airport
Battle Creek, Michigan

Well Location ID	Installation Date	Top of Casing Elevation (ft amsl)[a]	Total Depth (ft btoc)[b]	Date Sampled	Water Elevation (ft. amsl)
ESMP-1S[c]	Aug-94	919.10	31.16	Aug-94	892.11
ESMP-1D[d]	Aug-94	919.09	44.17	Aug-94	892.16
ESMP-2S	Aug-94	918.54	33.20	Aug-94	891.98
				Apr-98	891.64
ESMP-2D	Aug-94	918.48	43.79	Aug-94	891.97
				Apr-98	891.54
ESMP-2DD[e]	N/A[f]	N/A	N/A	Apr-98	NM[g]
ESMP-3S	Aug-94	918.20	30.40	Aug-94	891.69
				Jun-95	DRY
ESMP-3D	Aug-94	918.24	43.26	Aug-94	891.63
		918.24		Jun-95	NM
ESMP-3DD	Aug-94	918.14	56.29	Aug-94	891.36
				Jun-95	NM
ESMP-4S	Aug-94	916.95	29.84	Aug-94	891.45
				Jun-95	DRY
				Apr-98	891.25
ESMP-4D	Aug-94	916.83	42.90	Aug-94	891.17
				Jun-95	DRY
				Apr-98	891.23
ESMP-5S	Aug-94	916.38	26.18	Aug-94	891.27
ESMP-5D	Aug-94	916.39	39.98	Aug-94	891.16
ESMP-6S	Aug-94	915.39	26.43	Aug-94	890.77
ESMP-6D	Aug-94	915.31	40.00	Aug-94	890.64
ESMP-7S	Aug-94	917.10	28.59	Aug-94	891.57
ESMP-7D	Aug-94	917.18	40.52	Aug-94	891.61
ESMP-8S	Aug-94	921.11	31.99	Aug-94	892.68
ESMP-8D	Aug-94	920.98	45.07	Aug-94	892.44
ESMP-9S	Aug-94	918.95	28.12	Aug-94	892.04
ESMP-10S	Aug-94	917.66	27.43	Aug-94	891.81
ESMP-10D	Aug-94	917.67	41.99	Aug-94	891.82
ESMP-11S	Aug-94	911.20	27.79	Aug-94	890.32
ESMP-11D	Aug-94	911.18	43.88	Aug-94	890.33
ESMP-12S	Aug-94	914.32	32.49	Aug-94	889.18
ESMP-12D	Aug-94	914.47	51.34	Aug-94	889.41
ESMP-13S	Aug-94	918.72	30.59	Aug-94	NM
BC3-MW1	Nov-88	923.16	42.26	Aug-94	892.80
BC3-MW2	Nov-88	920.73	41.03	Aug-94	892.19
				Jun-95	891.80
BC3-MW3	Nov-88	920.30	40.90	Aug-94	892.22
BC3-MW4	Nov-88	920.42	70.32	Aug-94	891.62
				Jun-95	891.20
				Apr-98	891.52
BC3-MW5	Aug-89	920.28	41.54	Aug-94	890.25
BC3-MW6	Aug-89	913.42	35.00	Aug-94	890.10

[a] ft amsl = feet above mean sea level   [b] ft btoc = feet below top of casing
[c] Suffix "S" refers to "Shallow" screened interval of nested monitoring points
[d] Suffix "D" refers to "Deeper" screened interval of nested monitoring points
[e] Suffix "DD" refers to "Deepest Depth" screened interval of nested monitoring points
[f] N/A = Not Available   [g] NM = Not measured

s:es/remed/bioplume/45010/update/tables/WELL_DATA.xls location,water level

April 1998

June 1995

August 1994

FIGURE 2

GROUNDWATER ELEVATIONS

Site 3 (Fire Training Area)
Intrinsic Remediation TS Addendum
Michigan Air National Guard, W.K. Kellogg Airport
Battle Creek, Michigan

PARSONS
ENGINEERING SCIENCE, INC.
Denver, Colorado

LEGEND

ESMP-2S Groundwater Monitoring Well/Point
891.98   Water Level Elevation
         (feet above mean sea level)

892 Groundwater Elevation Isopleth
     (dashed where inferred)

Fire Training Area

Bioventing Well (VW-1)

Inferred Direction of Groundwater Flow

NA Not Available

0   75   150
      Feet

determined for monitoring well BC3-MW4 in April 1998 was lower than the elevation measured in August 1994 and higher than the June 1995 elevation.

In August 1994, horizontal and vertical gradients were determined for groundwater at Site 3. A horizontal gradient of approximately 0.003 foot per foot (ft/ft) to the northwest was calculated. Downward vertical gradients ranging from 0.001 to 0.021 ft/ft were measured in monitoring points ESMP-1 through ESMP-6, which are in the vicinity of, or directly down gradient from, the fire training pit. Upward vertical gradients ranging from 0.001 to 0.012 ft/ft were measured in areas west and northwest of the fire training pit (Parsons ES, 1995). There are insufficient data to determine temporal changes in horizontal or vertical hydraulic gradients at Site 3.

2.2 BTEX In Groundwater

Results of analysis for dissolved fuel hydrocarbon compounds in groundwater at Site 3 are presented in Table 3, and the distributions of BTEX in groundwater in August 1994, June 1995, and April 1998 are presented on Figure 3. The results of the August 1994 groundwater sampling identified a BTEX plume emanating from the fire training pit and traveling toward the northwest. As a result of a limited number of sampling points in both June 1995 and April 1998, isopleths for these sampling events can not be accurately determined. However, the BTEX concentration trends at individual wells/points can be evaluated.

The temporal variations in dissolved BTEX concentrations at monitoring wells/points BC3-MW2, BC3-MW3, BC3-MW4, ESMP-2S, ESMP-2D, and ESMP-3D are presented on Figure 4. Available data for previous sampling events in 1989 and 1991 (Parsons ES, 1994) are incorporated for comparison. Temporal data for BTEX in groundwater indicates that concentrations of dissolved BTEX have decreased at all monitoring wells/points sampled except BC3-MW4. BTEX was not detected at ESMP-2S and ESMP-2D in April 1998, which represents a significant decrease from concentrations of 7.2 and 26.1 micrograms per liter (μg/L), respectively, measured in August 1994. Concentrations of BTEX at monitoring point ESMP-3D decreased from 16.8 μg/L to less than the reporting limit of 1 μg/L between August 1994 and April 1998. At monitoring well BC3-MW2, located directly downgradient of the source area and the bioventing well, the concentration of BTEX in the groundwater was reduced from 1,520 μg/L in 1991 to 18.5 μg/L in June 1995.

The decrease of BTEX in groundwater at BC3-MW2, ESMP-2S, and ESMP-2D indicates that the bioventing system at Site 3 is effectively reducing fuel hydrocarbon contamination in groundwater near the source area. Monitoring well BC3-MW4 is the only sampling location that had an increase in the concentration of fuel hydrocarbon compounds in groundwater. BC3-MW4 is located downgradient from the source area and bioventing well, and may be located outside the area of influence of the bioventing system. While the data support a decrease in source area BTEX concentrations, insufficient data are available to determined spatial or temporal trends in BTEX concentrations downgradient of well BC3-MW4.

S:\ES\WP\PROJECTS\722450\BATTLE CREEK\1.DOC

TABLE 3
FUEL HYDROCARBON COMPOUNDS DETECTED IN GROUNDWATER
Site 3 (Fire Training Area)
Intrinsic Remediation TS Addendum
Michigan Air National Guard W.K. Kellogg Airport
Battle Creek, Michigan

Well Location ID	Date Sampled	Benzene (μg/L)a	Toluene (μg/L)	Ethylbenzene (μg/L)	m+p-Xylene (μg/L)	o-Xylene (μg/L)	Total Xylenes (μg/L)	Total BTEX (μg/L)	1,3,5-TMBb (μg/L)	1,2,4-TMB (μg/L)	1,2,3-TMB (μg/L)	1,2,4,5-TeMBc (μg/L)	1,2,3,5-TeMB (μg/L)	1,2,3,4-TeMB (μg/L)	Fuel Carbon (μg/L)
ESMP-1S	Aug-94	25.9	4.3	123	863	100	963	1,116	112	223	163	NAe	NA	NA	NA
ESMP-1D	Aug-94	<1d	2.2	<1	2.2	<1	2.2	4.4	<1	1.6	1.1	NA	NA	NA	NA
ESMP-2S	Aug-94	<1	<1	2.6	4.6	<1	4.6	7.2	<1	3.7	4.7	NA	NA	NA	NA
ESMP-2D	Apr-98	NDb	ND	ND	ND	ND	ND	ND	ND	ND	ND	NA	NA	NA	NA
ESMP-2D	Aug-94	<1	<1	2.9	20.1	3.1	23.2	26.1	3.1	7.1	4.8	NA	NA	NA	NA
ESMP-2DD	Apr-98	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	NA	NA	NA	NA
ESMP-3S	Aug-94	<1	<1	ND	3.9	<1	3.9	3.9	<1	2.0	1.4	NA	NA	NA	NA
ESMP-3D	Aug-94	<1	<1	1.7	12.9	2.2	15.1	16.8	2.3	5.4	3.9	NA	NA	NA	NA
ESMP-3DD	Jun-95	<1	ND	ND	ND	ND	ND	<1	ND	ND	ND	NA	NA	NA	<1
ESMP-3DD	Aug-94	<1	<1	<1	<1	<1	<1	<1	ND	1.5	1.2	NA	NA	NA	ND
ESMP-4S	Aug-94	<1	<1	<1	4.2	<1	4.2	4.2	1.0	2.5	1.7	NA	NA	NA	NA
ESMP-4D	Aug-94	<1	<1	<1	1.1	<1	1.1	1.1	<1	1.3	1.0	NA	NA	NA	NA
ESMP-5S	Aug-94	<1	1.40	<1	1.4	<1	1.4	2.8	<1	2.7	1.6	NA	NA	NA	NA
ESMP-5D	Aug-94	<1	<1	<1	1.9	<1	1.9	1.9	<1	1.5	1.0	NA	NA	NA	NA
ESMP-6S	Aug-94	<1	<1	<1	1.9	<1	1.9	1.9	<1	1.6	1.0	NA	NA	NA	NA
ESMP-6D	Aug-94	<1	<1	<1	<1	<1	<1	<1	<1	1.0	<1	NA	NA	NA	NA
ESMP-7S	Aug-94	12.4	1.1	10.2	25.4	<1	25.4	49.1	<1	28.1	18.8	NA	NA	NA	NA
ESMP-7D	Aug-94	4.2	<1	5.1	2.1	<1	2.1	11.4	<1	1.8	<1	NA	NA	NA	NA
ESMP-8S	Aug-94	<1	<1	<1	4.1	<1	4.1	4.1	<1	2.3	1.5	NA	NA	NA	NA
ESMP-8D	Aug-94	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	NA	NA	NA	NA
ESMP-9S	Aug-94	<1	<1	<1	3.2	<1	3.2	3.2	<1	1.6	1.2	NA	NA	NA	NA
ESMP-10S	Aug-94	2.0	2.3	5.6	10.4	3.3	13.7	23.6	35.8	4.8	16.9	NA	NA	NA	NA
ESMP-10D	Aug-94	<1	<1	<1	<1	<1	<1	<1	1.0	1.0	1.0	NA	NA	NA	NA
ESMP-11S	Aug-94	<1	<1	<1	2.2	<1	2.2	2.2	1.1	1.8	1.3	NA	NA	NA	NA
ESMP-11D	Aug-94	<1	1.0	<1	<1	<1	1.0	1.0	<1	1.0	1.0	NA	NA	NA	NA
ESMP-12S	Aug-94	<1	1.0	<1	1.2	<1	1.2	2.2	1.0	1.1	1.0	NA	NA	NA	NA
ESMP-12D	Aug-94	<1	1.0	<1	<1	<1	<1	1.0	<1	1.0	<1	NA	NA	NA	NA
ESMP-13S	Aug-94	<1	<1	<1	<1	<1	<1	<1	<1	1.0	1.0	NA	NA	NA	NA
BC3-MW1	1989	ND	ND	ND	NA	NA	ND	ND	NA	NA	NA	NA	NA	NA	NA
	1991	ND	ND	ND	NA	NA	ND	ND	NA	NA	NA	NA	NA	NA	NA
	Aug-94	<1	<1	<1	<1	<1	<1	<1	1.0	1.3	1.0	NA	NA	NA	NA
BC3-MW2	1989	56	ND	26	NA	NA	110	192	NA	NA	NA	NA	NA	NA	NA
	1991	200	240 Jd	100	NA	NA	980	1,520	NA	NA	NA	NA	NA	NA	NA
	Aug-94	1.6	<1	5.5	12.8	1.0	13.8	20.9	3.0	15.4	9.5	NA	NA	NA	NA
	Jun-95	8.57	<1	6.47	3.48	<1	3.48	18.5	ND	9.01	5.41	1.36	1.74	2.36	97.1
BC3-MW3	1989	ND	ND	ND	NA	NA	ND	ND	NA	NA	NA	NA	NA	NA	NA
	1991	0.18 J	0.58	0.2 J	NA	NA	0.7 J	1.66	NA	NA	NA	NA	NA	NA	NA
	Aug-94	<1	<1	<1	<1	<1	<1	<1	<1	1.0	1.0	NA	NA	NA	NA
BC3-MW4	1989	ND	ND	ND	NA	NA	ND	ND	NA	NA	NA	NA	NA	NA	NA
	1991	ND	0.43	ND	NA	NA	1.1	1.43	NA	NA	NA	NA	NA	NA	NA
	Aug-94	<1	<1	<1	<1	<1	<1	<1	<1	1.0	1.0	NA	NA	NA	NA
	Jun-95	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	Apr-98	<1	<1	2.8	10.5	<1	10.5	13.3	1.6	5.1	2.5	NA	NA	NA	NA
BC3-MW5	1989	ND	ND	ND	NA	NA	ND	ND	NA	NA	NA	NA	NA	NA	NA
	1991	ND	ND	ND	NA	NA	ND	ND	NA	NA	NA	NA	NA	NA	NA
	Aug-94	<1	<1	<1	<1	<1	<1	<1	<1	1.0	<1	NA	NA	NA	NA
BC3-MW6	1989	ND	ND	ND	NA	NA	ND	ND	NA	NA	NA	NA	NA	NA	NA
	Aug-94	<1	<1	<1	<1	<1	<1	<1	<1	1.0	1.0	NA	NA	NA	NA

a μg/L = micrograms per liter.
b TMB = Trimethylbenzene.
c TeMB = Tetramethylbenzene.
d <1 = Analyte detected below the limit of quantitation (1 μg/L).
e NA = Not analyzed.
b ND = Not detected.
f J = Estimated Value.

s:es/remed/bioplume/45010/updatetables/WELL_DATA.xls fuel hydrocarbons (11x17)

April 1998

ND   Non-Detect

June 1995

August 1994

FIGURE 3

TOTAL BTEX CONCENTRATIONS IN GROUNDWATER

Site 3 (Fire Training Area)
Intrinsic Remediation TS Addendum
Michigan Air National Guard, W.K. Kellogg Airport
Battle Creek, Michigan

PARSONS ENGINEERING SCIENCE, INC.

Denver, Colorado

LEGEND

ESMP-2D   Groundwater Monitoring Well/Point
26.1   BTEX Concentration
          (micrograms per liter)

—10—   Total BTEX Contour

          Fire Training Area

          Bioventing Well (VW-1)

ND   Non-Detect

NOTE: The highest BTEX concentration at any well cluster is posted and contoured.

0   75   150
        Feet

FILE NAM: :FS\REMED\BIOPLUME\45010\UPDATE\MAP_INFO\BTEX.WOR   DATE: 6/1.
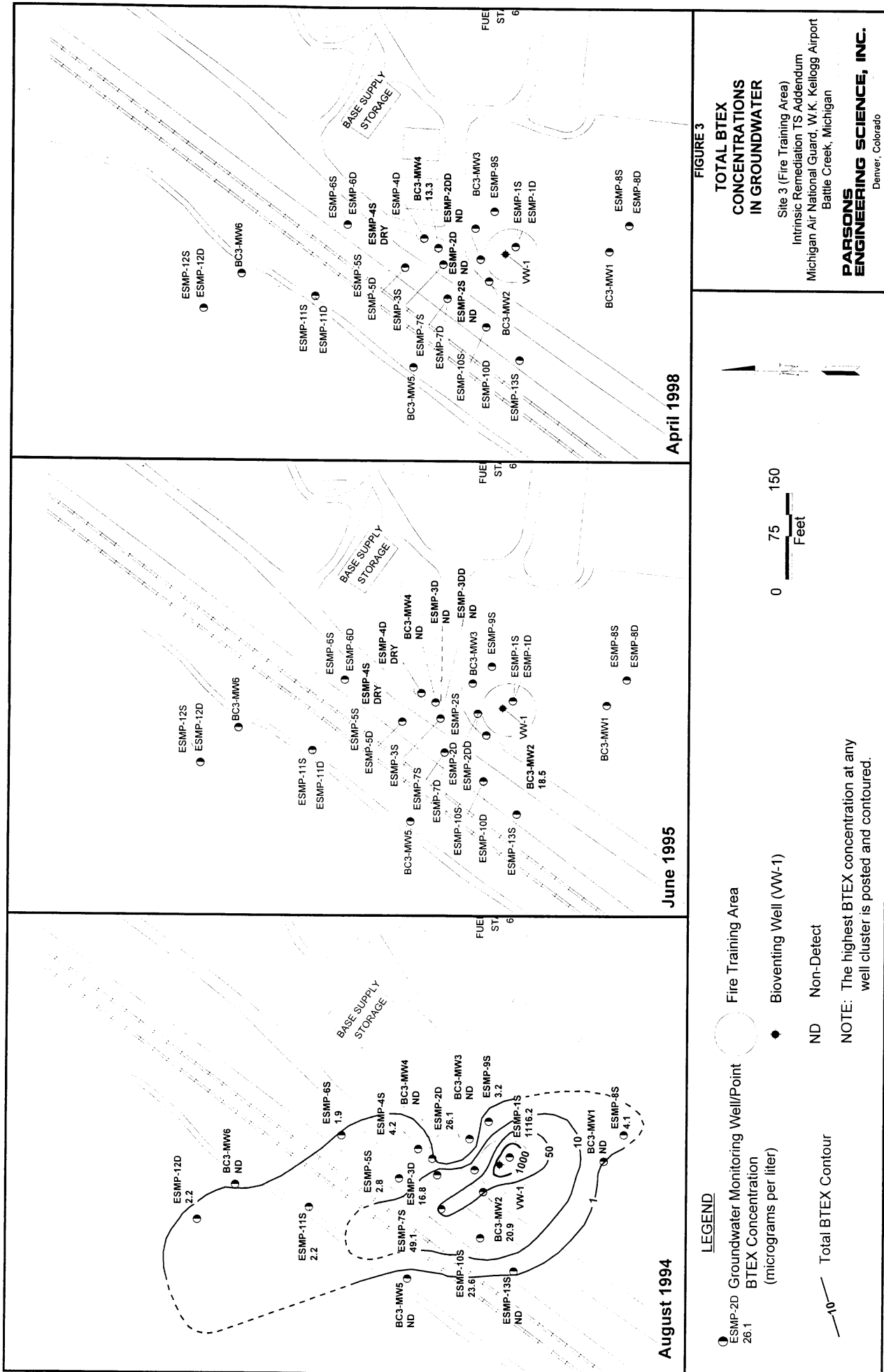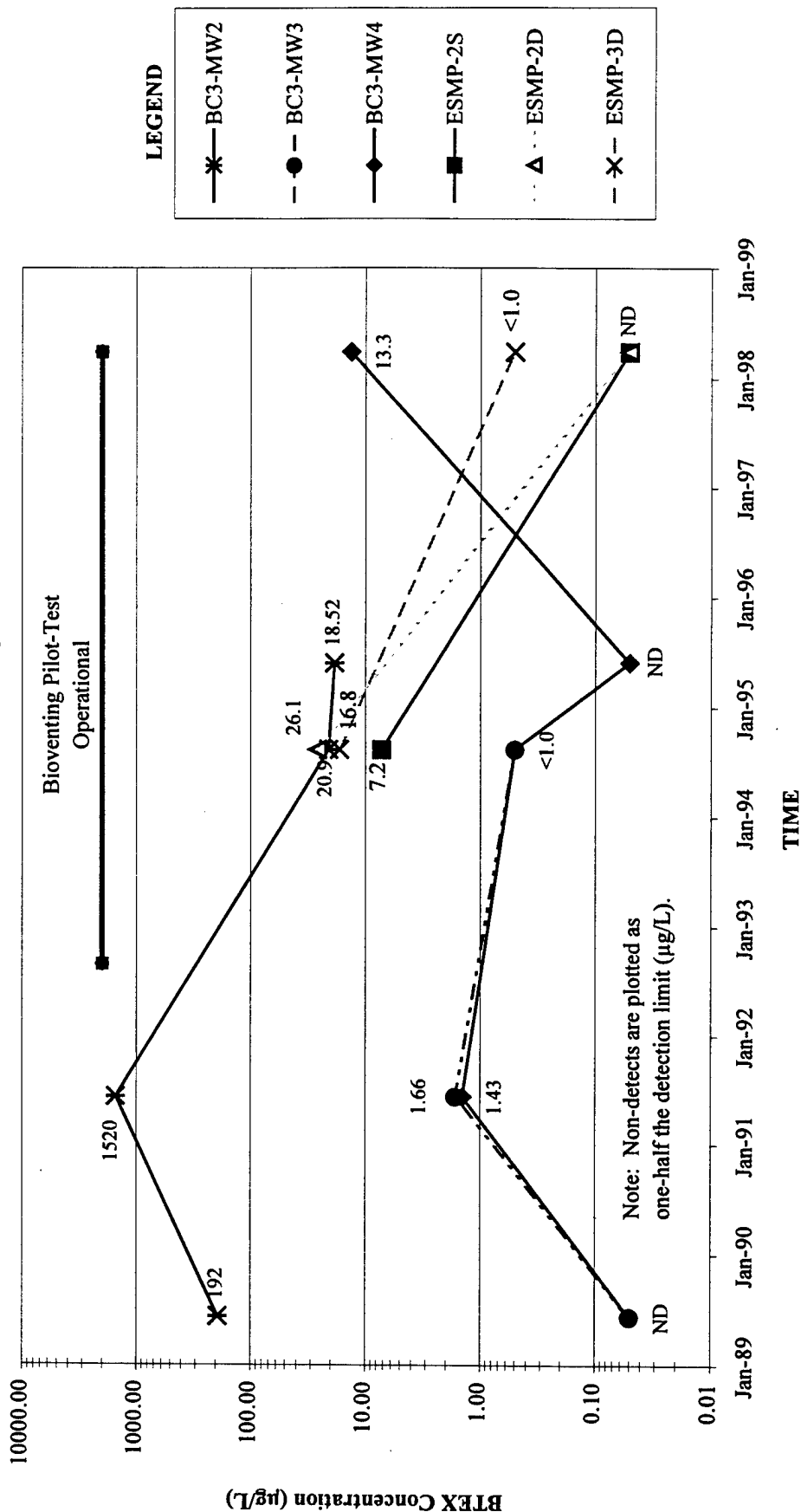
FIGURE 4
PLOT OF TOTAL BTEX VERSUS TIME

Site 3 (Fire Training Area)
Intrinsic Remediation TS Addendum
Michigan Air National Guard W.K. Kellogg Airport
Battle Creek, Michigan

6/16/99

2.3 Chlorinated Aliphatic Hydrocarbons

In addition to fuel hydrocarbons, an undetermined quantity of organic solvents (CAHs) were also used at Site 3 during fire training activities. An analysis of CAH biodegradation was not included in the TS scope, but a discussion of CAH biodegradation is included in this addendum in Section 2.6.

Of the CAHs analyzed for in August 1994, June 1995, and April 1998, tetrachloroethene (PCE), trichloroethene (TCE), and cis-1,2-dichloroethene (cis-1,2-DCE) were the only organic solvents detected at or above laboratory reporting limits. Table 4 summarizes the CAH concentrations detected in groundwater at Site 3.

PCE and TCE were detected at concentrations ranging up to 2.5 μg/L and 2.3 μg/L, respectively. The chlorinated compound most commonly detected during the three rounds of sampling at Site 3 was cis-1,2-DCE. Concentrations of cis-1,2-DCE at Site 3 coincide with elevated concentrations of total BTEX in groundwater. The USEPA drinking water maximum contaminant level (MCL) for cis-1,2-DCE is 70 μg/L. The highest concentration of cis-1,2-DCE detected in August 1994 was 117 μg/L at monitoring point ESMP-7S. No additional data have been collected since August 1994 at monitoring point ESMP-7S to determine temporal trends. Concentrations of cis-1,2-DCE at monitoring well BC3-MW2 increased between August 1994 and June 1995 from 9.8 to 75.2 μg/L. In April 1998, CAHs were not detected above reporting limits at any of the sampled wells.

2.4 Inorganic Chemistry and Geochemical Indicators of BTEX Biodegradation

As discussed in the TS, microorganisms obtain energy for cell production and maintenance by facilitating thermodynamically advantageous oxidation/reduction reactions involving the transfer of electrons from electron donors to available electron acceptors. This results in the oxidation of the electron donor and the reduction of the electron acceptor. Electron donors at Site 3 are natural organic carbon and fuel hydrocarbon compounds. Fuel hydrocarbons are completely degraded or detoxified if they are utilized as the primary electron donor for microbial metabolism (Bouwer, 1992).

Electron acceptors are elements or compounds that occur in relatively oxidized states and include oxygen, nitrate, ferric iron hydroxides, sulfate, and carbon dioxide. Microorganisms preferentially utilize electron acceptors while metabolizing fuel hydrocarbons (Bouwer, 1992). DO is utilized first as the prime electron acceptor. After the DO is consumed, anaerobic microorganisms use electron acceptors in the following order of preference: nitrate, ferric iron, sulfate, and finally carbon dioxide. Anaerobic destruction of the BTEX compounds is associated with the accumulation of fatty acids, production of methane, solubilization of iron (ferrous iron), and reduction of nitrate and sulfate (Cozzarelli et al., 1990; Wilson et al., 1990).

In the TS it was suggested that methanogenesis has the greatest potential as an anaerobic mechanism for BTEX oxidation at the site. In addition, denitrification, iron reduction, and sulfate reduction are potentially responsible for approximately 22 percent of the BTEX mass reduction capacity of the groundwater system. Likewise, a decrease in DO concentrations at

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TABLE 4
DETECTED CAHs IN GROUNDWATER
Site 3 (Fire Training Area)
Intrinsic Remediation TS Addendum
Michigan Air National Guard W.K. Kellogg Airport
Battle Creek, Michigan

Well Location ID	Date Sampled	PCE[a/] (µg/L)[d/]	TCE[b/] (µg/L)	cis-1,2-DCE[c/] (µg/L)	Total Chlorinated Ethenes (µg/L)
MCL[e/]		5	5	70	
ESMP-1S	Aug-94	1.5	<1[f/]	22.7	24.2
ESMP-1D	Aug-94	<1	<1	<1	<1
ESMP-2S	Aug-94	<1	<1	1.0	1.0
	Apr-98	<1	ND[g/]	ND	<1
ESMP-2D	Aug-94	<1	<1	<1	<1
	Apr-98	ND	ND	ND	ND
ESMP-2DD	Apr-98	ND	ND	ND	ND
ESMP-3S	Aug-94	2.5	<1	<1	2.5
ESMP-3D	Aug-94	<1	<1	<1	<1
	Jun-95	ND	ND	ND	ND
ESMP-3DD	Aug-94	<1	<1	<1	<1
	Jun-95	ND	ND	ND	ND
ESMP-4S	Aug-94	<1	<1	<1	<1
	Apr-98	ND	ND	ND	ND
ESMP-4D	Aug-94	<1	2.3	<1	2.3
	Apr-98	ND	ND	ND	ND
ESMP-5S	Aug-94	2.0	<1	<1	2.0
ESMP-5D	Aug-94	<1	<1	1.6	1.6
ESMP-6S	Aug-94	<1	<1	<1	<1
ESMP-6D	Aug-94	<1	<1	<1	<1
ESMP-7S	Aug-94	1.8	1.1	117	119.9
ESMP-7D	Aug-94	<1	<1	29.2	29.2
ESMP-8S	Aug-94	<1	<1	<1	<1
ESMP-8D	Aug-94	<1	<1	<1	<1
ESMP-9S	Aug-94	<1	<1	<1	<1
ESMP-10S	Aug-94	<1	<1	1.0	1.0
ESMP-10D	Aug-94	<1	<1	<1	<1
ESMP-11S	Aug-94	<1	2.0	<1	2.0
ESMP-11D	Aug-94	<1	<1	<1	<1

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TABLE 4 (Concluded)
DETECTED CAHs IN GROUNDWATER
Site 3 (Fire Training Area)
Intrinsic Remediation TS Addendum
Michigan Air National Guard W.K. Kellogg Airport
Battle Creek, Michigan

Well Location ID	Date Sampled	PCE[a/] (μg/L)[d/]	TCE[b/] (μg/L)	cis-1,2-DCE[c/] (μg/L)	Total Chlorinated Ethenes (μg/L)
MCL[e/]		5	5	70	
ESMP-12S	Aug-94	<1[f/]	2.2	<1	2.2
ESMP-12D	Aug-94	<1	<1	<1	<1
ESMP-13S	Aug-94	<1	<1	<1	<1
BC3-MW1	Aug-94	<1	<1	<1	<1
BC3-MW2	Aug-94	<1	<1	9.8	9.8
	Jun-95	ND[g/]	ND	75.2	75.2
BC3-MW3	Aug-94	1.1	<1	<1	1.1
BC3-MW4	Aug-94	<1	<1	<1	<1
	Jun-95	ND	ND	ND	ND
BC3-MW5	Aug-94	<1	<1	<1	<1
BC3-MW6	Aug-94	<1	<1	<1	<1

[a/] PCE = Tetrachloroethene.

[b/] TCE = Trichloroethene.

[c/] cis-1,2-DCE = cis-1,2-Dichloroethene.

[d/] μg/L = micrograms per liter.

[e/] MCL indicates the maximum contaminant level for contaminants in drinking water as directed by the USEPA (1996).

[f/] Analyte detected below the limit of quantitation (1 μg/L).

[g/] ND = Not Detected.

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and downgradient of the source area compared to background concentrations indicates that aerobic respiration is occurring at an appreciable level, particularly at the plume periphery. Operation of the bioventing system is expected to change source area vadose zone conditions from anaerobic to aerobic. Geochemical parameters for the site groundwater are listed in Table 5 and discussed below. Significant geochemical indicators at Site 3 include ORP, DO, nitrate+nitrite, ferrous iron, sulfate and methane, which were analyzed at 4 wells in both June 1995 and April 1998.

2.4.1 Oxidation Reduction Potential

ORP, a measure of the relative tendency of a solution to accept or transfer electrons, was measured at select locations in June 1995 and April 1998. The dominant electron acceptor being reduced by microbes during BTEX oxidation is related to the ORP of the groundwater. The measured ORP increased from 1994 to 1995 or 1998 at monitoring wells ESMP-2D (-238 to 221 millivolts [mV]), ESMP-3D (-203.1 to 160 mV), ESMP-3DD (-200.9 to -130 mV), ESMP-4D (-10.9 to 142 mV), and BC3-MW4 (-14.7 - -60 to 107 mV), indicating increasingly oxidized groundwater at the site. While the measurement of ORP in the field is sensitive to sampling protocol and equipment, the increase in ORP is interpreted to be a result of decreased microbial activity due to decreasing dissolved BTEX concentrations. The decrease in dissolved BTEX concentrations can be attributed to natural attenuation and remediation of the vadose zone and capillary fringe via bioventing.

In contrast, a decrease in ORP was observed in the samples collected from well BC3-MW2 [-60 to -90 mV]. BTEX concentrations at this well remained relatively unchanged (decreased from 20.9 μg/L to 19 μg/L).

The range of ORP measured in June 1995 and April 1998 (-130 to 160 mV) indicate that the redox processes of aerobic respiration, denitrification, and manganese reduction will be preferred over iron reduction, sulfate reduction and methanogenesis. However, many authors have noted that field redox potential data alone cannot be used to reliably predict the electron acceptors that may be operating at a site, because the platinum electrode probes are not sensitive to some redox couples (e.g., sulfate/sulfide) (Stumm and Morgan, 1981; Godsey, 1994; Lovley et al., 1994).

2.4.2 Dissolved Oxygen

In August 1994, DO concentrations ranged from 0.09 milligrams per liter (mg/L) to 6.87 mg/L. Areas with elevated BTEX concentrations in groundwater corresponded to areas of depleted DO (Parsons ES, 1995). With the exception of monitoring point ESMP-4D, there has been a general increase in groundwater DO concentrations at Site 3 between August 1994 and April 1998, suggesting that the site is becoming more aerobic with time. DO increased significantly at ESMP-2D (from 0.1 mg/L in August 1994 to 9.7 mg/L in June 1995), and to a lesser extent at ESMP-3D, ESMP-3DD, BC3-MW2, and BC3-MW4. This increase in DO is interpreted to be a result of decreasing microbial activity due to the influence of natural attenuation and operation of the bioventing system as described above for ORP. However, data collected in June 1995 and April 1998 does support the correlation of elevated BTEX

TABLE 5
GROUNDWATER GEOCHEMICAL DATA
Site 3 (Fire Training Area)
Intrinsic Remediation TS Addendum
Michigan Air National Guard W.K. Kellogg Airport
Battle Creek, Michigan

Well Location ID	Date Sampled	Temperature (°C)[b]	pH	Specific Conductivity (µmhos/cm)[b]	Dissolved Oxygen (mg/L)[b]	Redox Potential (mV)[b]	Total Alkalinity (mg/L)	Hydrogen Sulfide (mg/L)	Ferrous Iron (mg/L)	Chloride (mg/L)	Sulfate (mg/L)	NO2+NO3 as Nitrogen[a] (mg/L)	TOC[a] (mg/L)	Methane (mg/L)	Ethane (mg/L)	Ethene (mg/L)	Ammonia (mg/L)	Carbon Dioxide (mg/L)	Manganese (mg/L)
ESMP-1S	Aug-94	19.1	6.79	917	0.12	-143.0	670	0.1	10.0	2.64	2.70	<0.05	53.9	4.228	0.019	<0.001	NA[c]	NA	NA
ESMP-1D	Aug-94	15.8	7.61	454	0.81	-110.9	200	NA	<0.1	1.77	7.96	2.49	0.7	0.004	ND[d]	ND	NA	NA	NA
ESMP-2S	Aug-94	16.7	8.08	532	0.86	-97.2	252	NA	2.0	1.51	5.60	1.27	2.0	0.066	<0.001	ND	NA	NA	NA
ESMP-2D	Apr-98	NA	7.4	NA	NA	NA	300	<0.1	0.1	77.5	11.8	2.09	NA	NA	NA	ND	<0.1	100	<0.1
ESMP-2D	Aug-94	14.8	7.54	466	0.1	-238.0	212	NA	0.6	2.05	14.7	1.24	0.7	0.003	<0.001	ND	NA	NA	NA
ESMP-2DD	Apr-98	13.2	7.3	604	9.7	221	320	<0.1	0.1	1.43	13	1.10	NA	ND	ND	ND	<0.1	55	<0.1
ESMP-3S	Apr-98	13.0	7.3	584	0.7	-123	360	<0.1	3.0	15.2	42	<0.1	NA	0.002	ND	ND	<0.1	45	<0.1
ESMP-3S	Aug-94	15.8	7.78	399	4.41	26.0	166	NA	0.1	6.68	12.8	1.48	0.9	<0.001	0.001	ND	NA	NA	NA
ESMP-3D	Apr-98	NA	NA	NA	NA	NA	NA	<0.1	NA	NA	NA	NA	NA	ND	NA	ND	<0.1	45	<0.1
ESMP-3D	Aug-94	15.8	7.73	409	0.33	-203.1	186	NA	0.2	2.07	8.59	2.24	0.7	0.003	0.001	ND	NA	NA	NA
ESMP-3DD	Jun-95	15.9	7.5	491	1.4	160	230	NA	<0.05	1.16	7.95	0.94	1.4	0.007	0.001	ND	NA	NA	NA
ESMP-3DD	Aug-94	13.8	7.42	564	0.09	-200.9	264	NA	3.0	5.57	23.7	<0.05	0.7	0.004	0.001	ND	NA	NA	NA
ESMP-4S	Jun-95	15.1	7.3	545	0.3	-130	243	NA	2.8	5.48	25.0	<0.05	0.9	0.001	NA	ND	NA	NA	NA
ESMP-4S	Aug-94	13.2	6.86	390	4.45	195.0	158	NA	<0.1	3.65	11.7	3.42	0.6	ND	ND	ND	NA	NA	NA
ESMP-4D	Apr-98	NA	NA	NA	NA	NA	NA	<0.1	NA	NA	NA	NA	NA	ND	ND	ND	<0.1	45	<0.1
ESMP-4D	Aug-94	12.7	8.93	455	3.99	-10.9	212	NA	<0.1	1.96	10.4	2.00	0.6	0.001	0.001	ND	NA	NA	NA
ESMP-5S	Aug-94	12.8	7.8	650	0.9	142	240	NA	<0.1	22.3	9.63	1.00	NA	0.004	0.004	ND	NA	NA	NA
ESMP-5D	Aug-94	20.4	8.25	340	6.11	48.2	132	NA	<0.1	12.8	9.70	0.31	5.2	0.007	0.002	ND	NA	NA	NA
ESMP-6S	Aug-94	13.6	7.31	438	0.25	-81.5	200	NA	<0.1	2.54	8.52	1.98	0.7	0.015	0.001	ND	NA	NA	NA
ESMP-6D	Aug-94	13.7	7.4	513	5.44	194.0	226	NA	<0.1	6.61	12.3	2.23	0.5	<0.001	ND	ND	NA	NA	NA
ESMP-7S	Aug-94	13	7.45	518	5.06	-6.7	232	NA	<0.1	7.36	13.1	2.50	0.5	0.003	0.001	ND	NA	NA	NA
ESMP-7D	Aug-94	17.2	7.28	600	0.27	-132.2	274	NA	5.0	7.21	6.45	1.34	15.6	0.829	0.004	ND	NA	NA	NA
ESMP-8S	Aug-94	14.2	7.25	480	0.7	-160.0	232	0.1	4.0	2.72	12.0	0.06	3.1	0.165	0.002	ND	NA	NA	NA
ESMP-8D	Aug-94	13.7	7.44	595	5.62	-70.0	286	NA	0.2	1.86	13.2	1.31	0.5	0.003	0.001	ND	NA	NA	NA
ESMP-9S	Aug-94	13.7	7.57	490	0.7	-95.0	228	NA	2.0	2.85	17.9	0.52	2.8	0.002	0.001	ND	NA	NA	NA
ESMP-10S	Aug-94	12.6	7.21	551	0.18	<-335	284	NA	0.1	2.44	1.82	0.06	1.1	0.157	0.001	ND	NA	NA	NA
ESMP-10D	Aug-94	13	7.27	626	0.32	<-314	282	NA	10.0	4.54	3.56	<0.05	6.9	0.614	0.003	ND	NA	NA	NA
ESMP-11S	Aug-94	13.2	7.68	467	2.37	-81.0	318	NA	0.2	3.25	13.2	1.00	12.4	0.003	0.001	ND	NA	NA	NA
ESMP-11D	Aug-94	12.4	7.63	479	6.6	103.6	210	NA	NA	11.9	15.8	1.5	1.4	<0.001	ND	ND	NA	NA	NA
ESMP-12S	Aug-94	13.5	7.66	412	0.1	<-170	212	NA	NA	1.80	15.6	0.4	4.2	0.002	0.001	ND	NA	NA	NA
ESMP-12D	Aug-94	12.4	7.57	467	4.44	65.2	204	NA	NA	5.21	12.7	1.5	1.2	0.002	0.001	ND	NA	NA	NA
ESMP-13S	Aug-94	17.5	7.48	547	1.3	-95.5	260	NA	0.1	5.05	27.3	NA	2.1	0.003	0.003	ND	NA	NA	NA
BC3-MW1	Aug-94	13.1	7.4	588	6.87	70.7	302	NA	1.5	2.72	8.73	1.00	1.0	0.003	0.001	ND	NA	NA	NA
BC3-MW2	Aug-94	14.4	7.42	528	0.12	-60.0	254	NA	3.0	4.64	21.8	<0.05	3.0	0.002	0.001	ND	NA	NA	NA
BC3-MW3	Aug-94	15.3	7.67	460	0.12	-60	212	NA	2.3	2.14	15.0	<0.05	5.0	0.393	NA	ND	NA	NA	NA
BC3-MW3	Jun-95	16.9	7.2	556	0.4	-90	268	NA	<0.1	1.58	10.1	0.69	8.0	1.30	ND	ND	NA	NA	NA
BC3-MW4	Aug-94	13.6	7.68	421	0.1	180.0	174	NA	0.2	1.77	9.81	1.00	0.3	<0.001	<0.001	ND	NA	NA	NA
BC3-MW4	Jun-95	13.8	7.51	495	0.27	-14.7	224	NA	0.5	2.90	22.8	0.06	0.9	<0.001	<0.001	ND	NA	NA	NA
BC3-MW5	Apr-98	14.7	7.6	504	0.3	-60	224	<0.1	<0.1	5.36	23.0	<0.05	0.8	0.003	0.003	ND	<0.1	15	<0.1
BC3-MW5	Aug-94	12.3	7.2	318	1	107	220	NA	<0.1	6.77	20	0.20	NA	ND	ND	ND	NA	NA	NA
BC3-MW6	Aug-94	12.7	7.36	440	5.78	255.0	194	NA	<0.1	1.65	11.1	2.13	19.0	ND	ND	ND	NA	NA	NA
BC3-MW6	Aug-94	14.3	7.12	545	0.1	-106.1	248	NA	3.0	4.70	22.9	0.05	1.9	<0.001	ND	ND	NA	NA	NA

[a] NO2+NO3 as Nitrogen = Nitrate + Nitrite as Nitrogen. TOC = Total Organic Carbon.
[b] °C = degree Celcius. µmhos/cm = micromhos per centimeter. mg/L = milligrams per liter. mV = millivolts.
[c] NA = Not analyzed.
[d] ND = Not detected.

and depleted DO at well locations BC3-MW2 and BC3-MW4. This correlation is a strong indication of the occurrence of aerobic biodegradation of BTEX at the site.

2.4.3 Nitrate+Nitrite

Of the seven monitoring wells/points sampled in both June 1995 and April 1998, concentrations of nitrate+nitrite (as nitrogen [N]) increased at three sampling locations, decreased at three locations, and remained the same at one location. The greatest decrease (2.24 mg/L to 0.94 mg/L) occurred in ESMP-3D between August 1994 and June 1995, while the greatest increase (1.27 mg/L to 2.09 mg/L) occurred between August 1994 and April 1998 at ESMP-2S. Overall, there is no clear temporal trend in nitrate+nitrite (as N) concentrations relative to BTEX concentrations.

2.4.4 Ferrous Iron

August 1994 concentrations of ferrous iron (Fe^{2+}) in groundwater corresponded with elevated BTEX concentrations (Parsons ES, 1995). For locations sampled in 1995 and 1998, concentrations of Fe^{2+} decreased except at ESMP-4D, where concentrations remained unchanged (<0.1 mg/L). The decrease in Fe^{2+}, combined with an increase in both ORP and DO, suggests that the occurrence of iron reduction has decreased within the area sampled in 1995 and 1998.

2.4.5 Sulfate

Since August 1994, there have been only slight changes in the concentration of sulfate in groundwater at Site 3. The only monitoring wells/points that exhibited any notable change were ESMP-2S and BC3-MW2. Sulfate concentrations increased from 5.60 to 11.8 mg/L at monitoring point ESMP-2S, possibly due to the lack of BTEX (i.e., an electron donor) at this sampling location. Conversely, at monitoring well BC3-MW2 sulfate concentrations decreased from 15.0 to 10.1 mg/L. The relative stability of sulfate concentrations suggests that sulfate reduction continues to occur as it was in 1994. However, the wells that exhibited the lowest sulfate concentrations in 1994 were not resampled in 1995 or 1998. Therefore, definitive conclusions regarding the continued occurrence of sulfate reduction cannot be made.

2.4.6 Methane

With the exception of data collected at monitoring well BC3-MW2, temporal data for methane in groundwater at Site 3 do not indicate a significant change in methane concentrations. Data collected at BC3-MW2 indicate an increase in methane concentrations from 0.393 to 1.30 mg/L between August 1994 and June 1995. These data suggest that methane continues to be produced as a result of fuel hydrocarbon biodegradation via methanogenesis at or near BC3-MW2.

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2.4.7 Alkalinity

Total alkalinity (as calcium carbonate) is a measure of the ability of water to buffer changes in pH. Biodegradation of BTEX produces carbon dioxide which, when mixed with water in the proper conditions, produces carbonic acid. In aquifers that have carbonate minerals as part of the matrix, carbonic acid dissolves these minerals, increasing the alkalinity of the groundwater. Therefore, an increase in alkalinity can be observed in areas of active biodegradation of BTEX. Total alkalinity of groundwater samples collected from August 1994 to April 1998 is summarized in Table 5.

Of the 10 wells with available alkalinity data for either June 1995 or April 1998, alkalinity increased at ESMP-2S, ESMP-2D, ESMP-3D, ESMP-4D, and BC3-MW2, and remained relatively constant at the other sampling locations. The data indicate that the alkalinity is sufficient to continue buffering the groundwater pH against the effects of biologically mediated BTEX oxidation reactions.

2.5 Biodegradation of Chlorinated Solvents

Chlorinated solvents can be transformed, directly or indirectly, by biological processes (e.g., Bouwer et al., 1981; Wilson and Wilson, 1985; Miller and Guengerich, 1982; Nelson et al., 1986; Bouwer and Wright, 1988; Little et al., 1988; Mayer et al., 1988; Arciero et al., 1989; Cline and Delfino, 1989; Freedman and Gossett, 1989; Folsom et al., 1990; Harker and Kim, 1990; Alvarez-Cohen and McCarty, 1991a and 1991b; DeStefano et al., 1991; Henry, 1991; McCarty et al., 1992; McCarty and Semprini, 1994; Vogel, 1994). Biodegradation of CAHs is similar in principle to biodegradation of BTEX as described in the March 1995 TS for Site 3; however, CAH degradation typically results from a more complex series of processes.

Whereas BTEX is biodegraded in essentially one step by acting as an electron donor/carbon source, CAHs may undergo biodegradation through three different pathways: use as an electron acceptor, use as an electron donor, or cometabolism, which is degradation resulting from exposure to a catalytic enzyme fortuitously produced during an unrelated microbial process. A fourth degradation mechanism that may occur is abiotic degradation, including hydrolysis and dehydrohalogenation reactions. However, attributing degradation of CAHs to abiotic processes is usually difficult, particularly at the field scale (Butler and Barker, 1996).

At a given site, one or all of these processes may be operating, although at many sites the use of CAHs as electron acceptors appears to be the most likely. A more complete description of the main types of biodegradation reactions affecting CAHs is presented in the following subsections.

2.5.1 Electron Acceptor Reactions (Reductive Dehalogenation)

Under anaerobic conditions, biodegradation of chlorinated solvents usually proceeds through a process called reductive dehalogenation. During this process, the halogenated hydrocarbon is used as an electron acceptor, not as a source of carbon, and a halogen atom is

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removed and replaced with a hydrogen atom. In general, reductive dehalogenation of chlorinated ethenes occurs by sequential dehalogenation from PCE to TCE to DCE to vinyl chloride (VC) to ethene as shown in Figure 5. Depending upon environmental conditions, this sequence may be interrupted, with other processes then acting upon the products. During reductive dehalogenation, all three isomers of DCE can theoretically be produced; however, Bouwer (1994) reports that under the influence of biodegradation, cis-1,2-DCE is a more common intermediate than trans-1,2-dichloroethene (trans-1,2-DCE), and that 1,1-DCE is the least prevalent intermediate of the three DCE isomers. Reductive dehalogenation of chlorinated solvent compounds is associated with the accumulation of daughter products and an increase in chloride.

Reductive dehalogenation affects each of the chlorinated ethenes differently. The rate of reductive dehalogenation has been observed to decrease as the degree of chlorination decreases (Vogel and McCarty, 1985; Bouwer, 1994). PCE is the most susceptible to reductive dehalogenation because it is the most oxidized. Conversely, VC is the least susceptible to reductive dehalogenation because it is the least oxidized of these compounds. Murray and Richardson (1993) have postulated that this rate decrease may explain the accumulation of VC in TCE plumes that are undergoing reductive dehalogenation.

In addition to being affected by the degree of chlorination of the CAH, reductive dehalogenation can also be controlled by the redox conditions of the site groundwater system. In general, reductive dehalogenation has been demonstrated under anaerobic nitrate- and sulfate-reducing conditions, but the most rapid biodegradation rates, affecting the widest range of CAHs, occur under methanogenic conditions (Bouwer, 1994). Dehalogenation of PCE and TCE to DCE can proceed under mildly reducing conditions such as nitrate reduction or ferric iron reduction (Vogel et al., 1987), while the transformation of DCE to VC, or the transformation from VC to ethene requires more strongly reducing conditions (Freedman and Gossett, 1989; DeStefano et al., 1991; DeBruin et al., 1992).

Because CAHs are used as electron acceptors, there must be an appropriate source of carbon for microbial growth in order for reductive dehalogenation to occur (Bouwer, 1994). Potential carbon sources can include low-molecular-weight compounds (e.g., lactate, acetate, methanol, or glucose) present in natural organic matter, or fuel hydrocarbons such as BTEX. At Site 3, ferric iron reduction, nitrate reduction, sulfate reduction, methanogenesis, and the corresponding low redox conditions in the core of contaminant plume as measured in August 1994 support the possibility that reductive dehalogenation has occurred at the site. This supposition is further supported by the presence of TCE daughter products in relatively large concentrations. In fact, cis-1,2-DCE (a daughter product of the reductive dehalogenation of TCE) is present more frequently and at higher concentrations than any other CAH at the site.

2.5.2 Electron Donor Reactions

Under aerobic conditions some CAH compounds can be utilized as the primary substrate (i.e., electron donor) in biologically mediated redox reactions (McCarty and Semprini, 1994). In this type of reaction, the facilitating microorganism obtains energy and organic carbon from the degraded CAH. In contrast to reactions in which the CAH is used as an electron
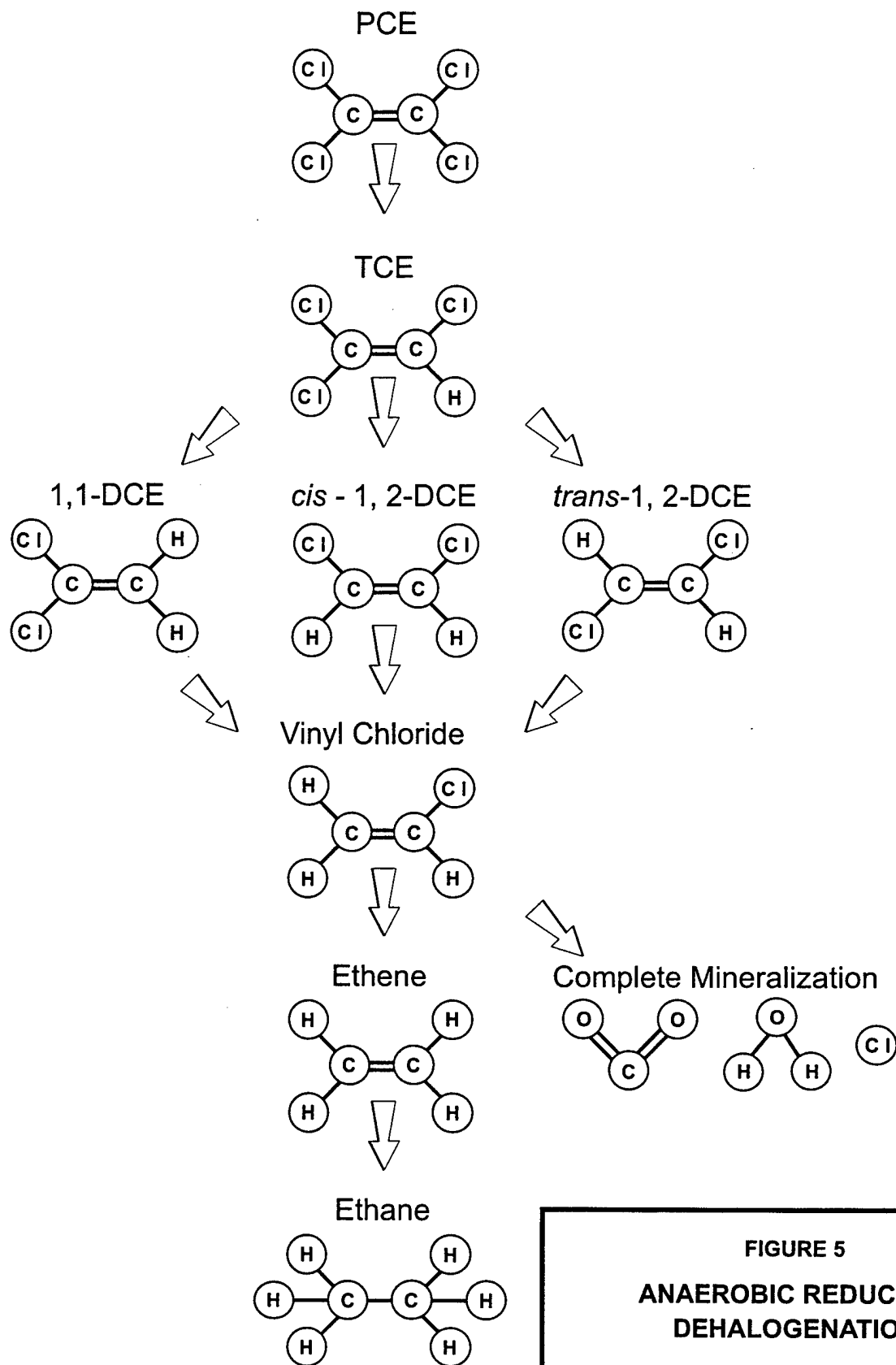
- 18 -

PCE

TCE

1,1-DCE   *cis* - 1, 2-DCE   *trans*-1, 2-DCE

Vinyl Chloride

Ethene   Complete Mineralization

Ethane

FIGURE 5

ANAEROBIC REDUCTIVE DEHALOGENATION

Site 3 (Fire Training Area)
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acceptor, only the least oxidized CAHs can be utilized as electron donors in biologically mediated redox reactions.

Aerobic degradation pathways for chlorinated ethenes are illustrated in Figure 6. Davis and Carpenter (1990) and McCarty and Semprini (1994) describe the aerobic oxidation of VC in groundwater. In addition, Bradley and Chapelle (1996) show evidence of oxidation of VC under iron-reducing conditions so long as there is sufficient bioavailable iron (III). Klier et al. (1996) write that naturally occurring microorganisms in soil and groundwater are capable of biodegrading DCE by using this compound as a primary substrate (i.e. an electron donor). Murray and Richardson (1993) write that microorganisms are generally believed to be incapable of growth using TCE and PCE. Aerobic oxidation of VC and DCE or reduction of VC under iron-reducing conditions may be characterized by contaminant mass loss, a decreasing molar ratio of DCE and/or VC to other CAH compounds, and the presence of elevated carbon dioxide concentrations.

2.5.3 Cometabolism

When a CAH is biodegraded through cometabolism, it serves as neither an electron acceptor nor a primary substrate in a biologically mediated redox reaction. Instead, the degradation of the CAH is catalyzed by an enzyme or cofactor that is fortuitously produced by organisms for other purposes. The organism receives no known benefit from the degradation of the CAH; rather, the cometabolic degradation of the CAH may in fact be harmful to the microorganism responsible for the production of the enzyme or cofactor (McCarty and Semprini, 1994).

Cometabolism is best documented in aerobic environments, although it potentially could occur under anaerobic conditions. It has been reported that under aerobic conditions chlorinated ethenes, with the exception of PCE, are susceptible to cometabolic degradation (Murray and Richardson, 1993; Vogel, 1994; McCarty and Semprini, 1994). Vogel (1994) further elaborates that the cometabolism rate increases as the degree of dehalogenation decreases. There is no site-specific evidence to either support or disallow that dissolved TCE, cis-1,2-DCE, and VC concentrations are being reduced through cometabolic processes.

2.5.4 Biodegradation of CAHs at Site 3

Concentrations of chlorinated ethenes versus distance from the source area (ESMP-1S) for August 1994 are shown on Figure 7 for PCE, TCE, and cis-1,2-DCE. From ESMP-1S to BC3-MW2, there is a decrease in the concentration of PCE coinciding with a lack of TCE and moderate concentrations of cis-1,2-DCE. The source area is characterized as an anaerobic zone, as determined by the low concentrations of DO (0.12 mg/L). Directly downgradient of the source area, at monitoring point ESMP-7S, there is a significant increase in the concentration of cis-1,2-DCE coinciding with low concentrations of both PCE and TCE. Between monitoring points ESMP-7S and ESMP-11S, and continuing downgradient to ESMP-12S, the concentration of DO increases significantly as the plume becomes aerobic. In this aerobic zone along the periphery of the plume, there is a slight increase in the persistence of TCE and a significant decrease in the concentration of cis-1,2-DCE.
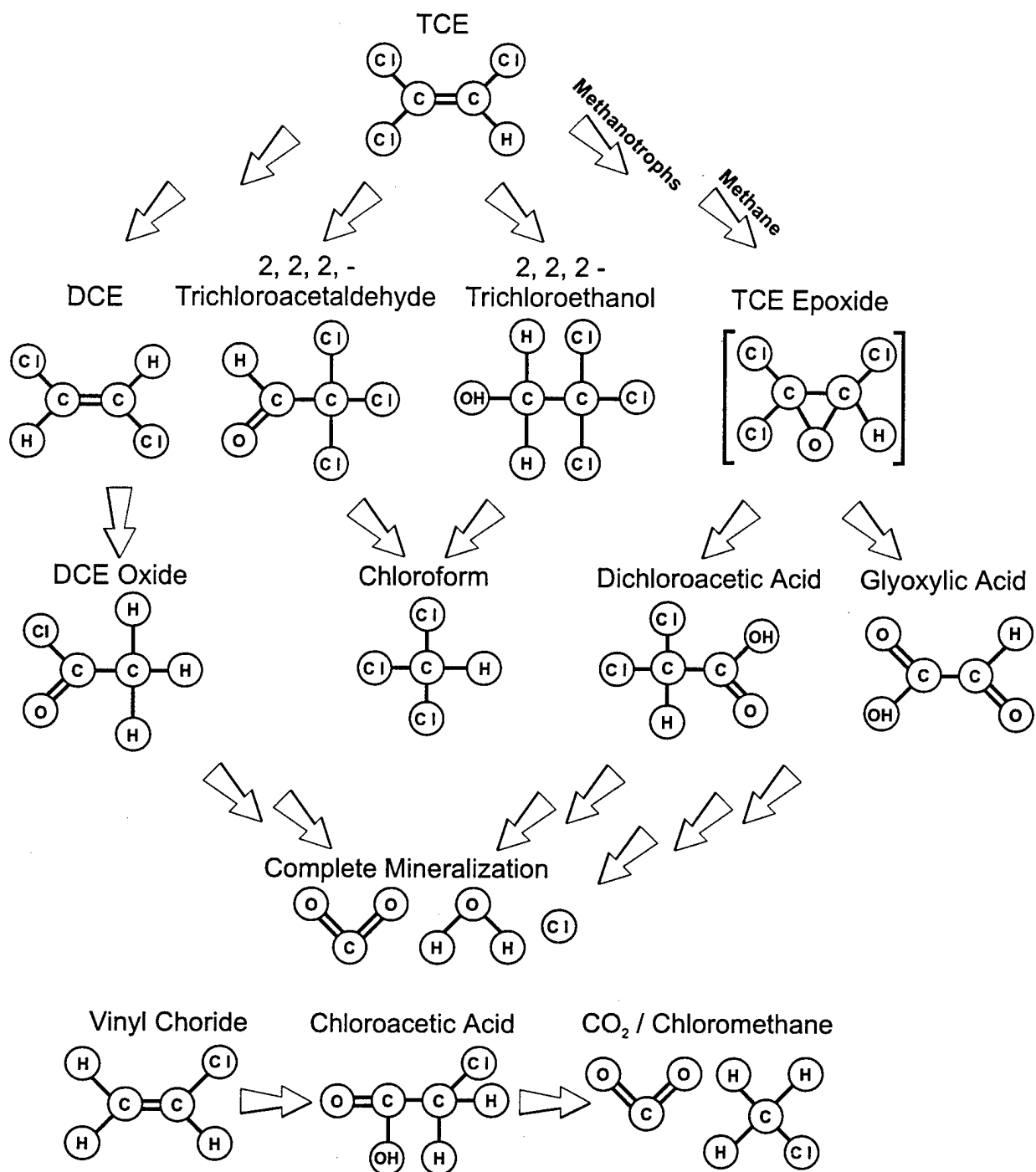
- 20 -

FIGURE 6

**AEROBIC
DEGRADATION PATHWAYS**

Site 3 (Fire Training Area)
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Battle Creek, Michigan

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FIGURE 7
CHLORINATED ETHENES VERSUS DISTANCE FROM SOURCE AREA
AUGUST 1994
Site 3 (Fire Training Area)
Intrinsic Remediation TS Addendum
Michigan Air National Guard W.K. Kellogg Airport
Battle Creek, Michigan

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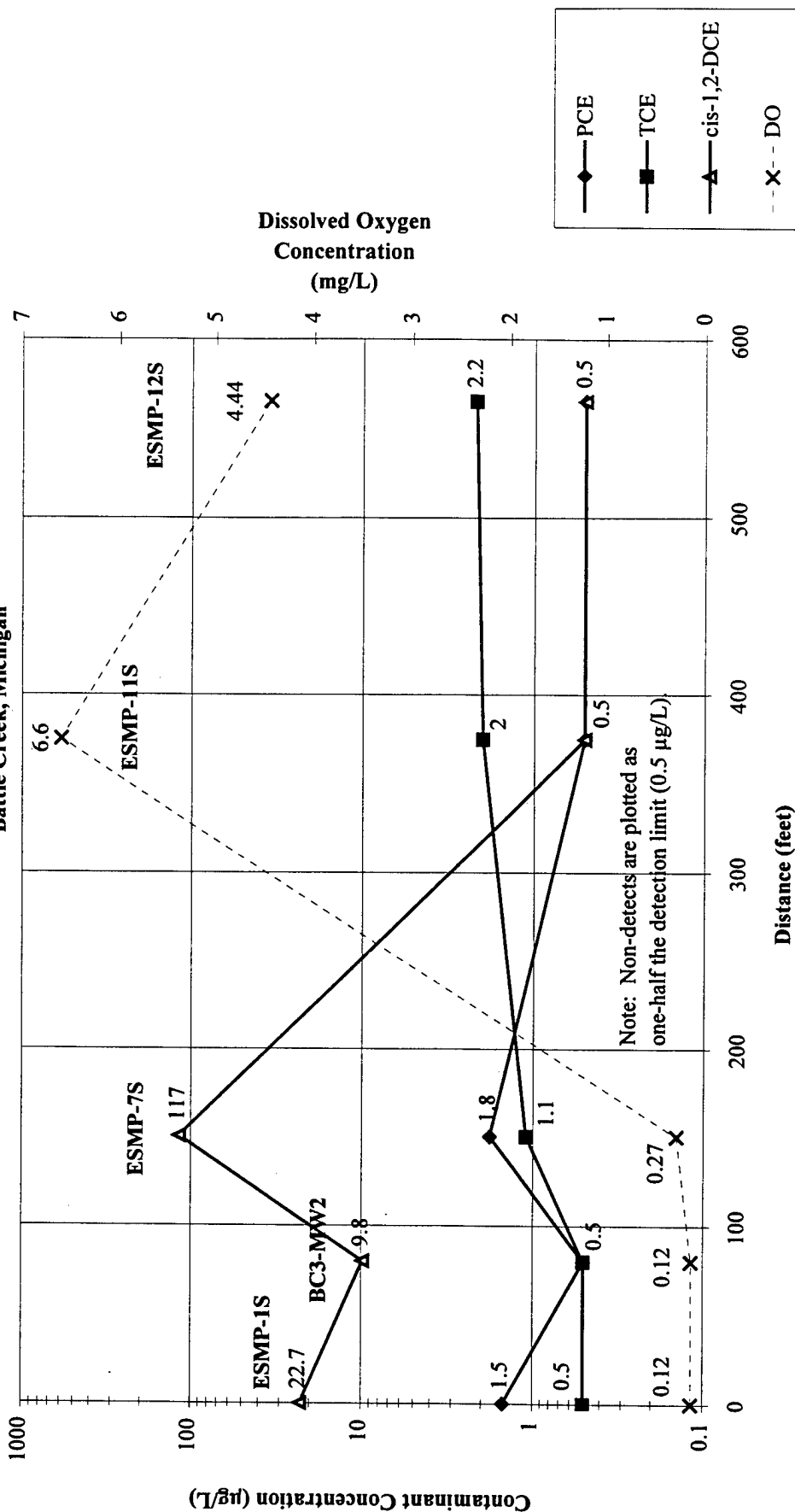
The distribution of chlorinated ethenes at Site 3 suggests that reductive dechlorination of PCE and TCE has occurred. The low concentrations of PCE and lack of TCE, combined with moderate concentrations of cis-1,2-DCE within the anaerobic source area, suggests that PCE is being reductively dehalogenated to TCE, which in turn is being completely degraded to cis-1,2-DCE. Data collected in June 1995 at monitoring well BC3-MW2 further supports this process, as evidenced by the lack of both PCE and TCE and an increase in the concentration of cis-1,2-DCE from 9.8 μg/L (August 1994) to 75.2 μg/L (June 1995). However, the lack of VC and ethene detections suggest that the groundwater system is not sufficiently reducing to cause the formation of significant concentrations of these byproducts. If VC is produced, it is rapidly degraded in the more aerobic zone downgradient from the source area.

At monitoring point ESMP-7S, located downgradient of the source area, 1994 data indicate that while reductive dechlorination of PCE and TCE may be occurring, the degradation to non-chlorinated end products is not complete, as evidenced by low concentrations of PCE and TCE and the accumulation of cis-1,2-DCE. Within the aerobic region of the plume, between monitoring points ESMP-7S, ESMP-11S, and ESMP-12S, the persistence of TCE indicates that this compound is no longer being degraded. However, the sharp decrease in cis-1,2-DCE downgradient of ESMP-7S, and the corresponding lack of VC, suggests that natural attenuation of cis-1,2-DCE is occurring by non-destructive mechanisms such as dispersion and sorption, and/or by aerobic biodegradation.

The degradation of PCE and TCE to cis-1,2-DCE is enhanced by anaerobic conditions induced by biodegradation of fuel hydrocarbons. This allows for the beneficial reductive dechlorination of CAHs near the source area. Beginning in August 1994, there have been only three detections of chlorinated ethenes that exceeded USEPA MCLs. Concentrations of cis-1,2-DCE at monitoring wells/points BC3-MW2 (75.2 μg/L) and ESMP-7S (117 μg/L) and at the vent well (1,410 μg/L) exceeded the USEPA (1996) MCL of 70 μg/L. As the chlorinated ethene plume migrates downgradient from ESMP-7S, aerobic conditions may favor degradation of cis-1,2-DCE, and minimize the migration and persistence of the compound in downgradient groundwater.

3.0 CONCLUSIONS AND RECOMMENDATIONS

As predicted by the Bioplume II simulations included in the TS (Parsons ES, 1995), the rate of BTEX loading to the groundwater appears to be decreasing due to natural attenuation and bioventing, and dissolved BTEX concentrations in the groundwater are generally decreasing. As of April 1998, concentrations of benzene in groundwater exceeded the USEPA MCL of 5 μg/L at only one sampling location (BC3-MW4, 13.3 μg/L). Temporal data for BTEX concentrations from monitoring wells/points at Site 3 confirms a decrease in the source area. However, there are insufficient data to determine temporal changes in the extent of the BTEX plume downgradient of BC3-MW4.

As a result of decreasing fuel hydrocarbon concentrations, microbial activity in the groundwater appears to be diminishing, as evidenced by increases in the groundwater ORP and DO concentrations, and decreasing ferrous iron concentrations. However, results of the

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update sampling events conducted in June 1995 and April 1998 continue to support the occurrence of natural attenuation of remaining dissolved BTEX at Site 3.

Although evidence of the degradation of fuel hydrocarbons at Site 3 is strong, a complete round of groundwater sampling is recommended to confirm the predicted results of the Bioplume II model, which indicates that dissolved BTEX compounds would degrade below detectable concentrations in 7 years.

Biodegradation of CAHs is supported by the low concentrations of parent compounds (TCE and PCE), the presence of *cis*-1,2-DCE within the anaerobic region of the BTEX plume, and the measured decrease in *cis*-1,2-DCE concentrations in the aerobic region further downgradient. Reducing conditions conducive to reductive dehalogenation result primarily from biodegradation of fuel hydrocarbons. The importance of reductive dehalogenation may decline as fuel hydrocarbon concentrations diminish and the groundwater system becomes more oxidizing.

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APPENDIX A

ANALYTICAL DATA

APPENDIX A

ANALYTICAL DATA

Ref: 95/JAD41

July 25, 1995

Dr. Don Kampbell
R.S. Kerr Environmental Research Lab
U.S. Environmental Protection Agency
P.O. Box 1198
Ada, OK 74820

THRU: S.A. Vandegrift SAV

Dear Don:

As requested in Service Request # SF-1-137, headspace GC/MS analysis of 4 Battle Creek water samples for VOC's was completed. The samples were received on June 20, 1995 and analyzed on June 30, 1995. RSKSOP-148 (Determination of Volatile Organic Compounds in Water by Automated Headspace Gas Chromatography/Mass Spectrometry (Saturn II Ion Trap Detector) was used for this analysis.

An internal standard calibration method was established for the 16 compounds. The standard curves were prepared from 1.0 to 2000 ppb. The lower calibration limits were 1.0 ppb.

A quantitation report for the samples, lab duplicates, field duplicates, QC standards and lab blanks is presented in table 1.

If you should have any questions, please feel free to contact me.

Sincerely,

John Allen Daniel

xc: R.L. Cosby
    G.B. Smith
    D.D. Fine
    J.L. Seeley

le 1. Quantitation Report for ⬤ . # SF-1-137 from Battle Creek.

Concentration = ppb

Compound	BC3MW2	BC3MW4	BC3MW4 Lab Dup	BC3MW4 Field Dup	ESMP3DD	ESMP3D	QC0630L 20 ppb	QC0630M 200 ppb	QC0710A 20 ppb	QC0710B 200 ppb
VINYL CHLORIDE	ND	ND	ND	ND	ND	ND	19.6	209	19.4	194
1,1-DICHLOROETHENE	ND	ND	ND	ND	ND	ND	21.9	224	22.7	210
T-1,2-DICHLOROETHENE	ND	ND	ND	ND	ND	ND	20.7	218	21.3	202
C-1,2-DICHLOROETHENE	75.2	ND	ND	ND	ND	ND	19.1	188	19.2	190
1,1,1-TRICHLOROETHANE	ND	ND	ND	ND	ND	ND	21.3	223	21.3	210
CARBON TETRACHLORIDE	ND	ND	ND	ND	ND	ND	21.1	228	21.0	204
BENZENE	7.4	ND	ND	ND	ND	ND	21.1	214	21.6	213
1,2-DICHLOROETHANE	ND	ND	ND	ND	ND	ND	19.0	177	19.3	202
TRICHLOROETHENE	ND	ND	ND	ND	ND	ND	21.4	216	20.9	205
TOLUENE	ND	ND	ND	ND	ND	ND	19.4	217	20.9	197
TETRACHLOROETHENE	ND	ND	ND	ND	ND	ND	20.1	217	20.8	189
CHLOROBENZENE	ND	ND	ND	ND	ND	ND	19.9	208	20.7	200
ETHYLBENZENE	5.2	ND	ND	ND	ND	ND	20.1	212	20.8	199
m+p-XYLENE	2.3	ND	ND	ND	ND	ND	21.0	229	21.4	198
o-XYLENE	ND	ND	ND	ND	ND	ND	20.2	219	20.5	202

Compound	BL0630A	BL0630B
VINYL CHLORIDE	ND	ND
1,1-DICHLOROETHENE	ND	ND
T-1,2-DICHLOROETHENE	ND	ND
C-1,2-DICHLOROETHENE	ND	ND
1,1,1-TRICHLOROETHANE	ND	ND
CARBON TETRACHLORIDE	ND	ND
BENZENE	ND	ND
1,2-DICHLOROETHANE	ND	ND
TRICHLOROETHENE	ND	ND
TOLUENE	ND	ND
TETRACHLOROETHENE	ND	ND
CHLOROBENZENE	ND	ND
ETHYLBENZENE	ND	ND
m+p-XYLENE	ND	ND
‑-XYLENE	ND	ND

ND = None Detected   QC = Quality Control Std   BL = Blank   Dup = Duplicate

MANAGEMENT
TECHNOLOGY

Dr. Don Kampbell
R.S. Kerr Environmental Research Lab
U.S. Environmental Protection Agency
919 Kerr Research Drive
Ada, OK 74820

THRU: Steve Vandegrift ⟨V

Dear Don:

Please find attached the analytical results for Service Request SF-1-137, Battle Creek AFB, requesting the analysis of up to 6 groundwater samples to be analyzed for BTEXXX, TriMBs, TetraMBs, and Total Fuel Carbon. A total of 4 samples were received, all in duplicate, in capped, 40 mL VOA vials on June 20, 1995. The samples were analyzed on June 21-22, 1995. All samples were acquired and processed using the Millennium data system. A 1-100 ppb external calibration curve was used to determine the concentration for the compounds.

RSKSOP-133 "Simultaneous Analysis of Aromatics and Total Fuel Carbon by Dual Column-Dual Detector for Ground Water Samples" was used for these analyses. Auto-sampling was performed using a Dynatech autosampler in-line with a Tekmar LSC 2000 sample concentrator.

Sincerely,

Lisa R. Black

Lisa R. Black

xc: R.L.Cosby
    G.B. Smith
    J. L. Seeley

ManTech Environmental Research Services Corporation

R.S. Kerr Environmental Research Laboratory, P.O. Box 1198, 919 Kerr Research Drive
Ada, Oklahoma 74821-1198   405-436-8660   FAX 405-436-8501

SampleName	BENZENE	TOLUENE	ETHYLBENZENE	p-XYLENE	m-XYLENE	o-XYLENE
10 PPB	10.31	10.26	10.29	10.24	10.26	10.23
QC, OBSERVED, PPB	47.23	48.85	51.38	47.22	47.23	50.43
QC, TRUE VALUE, PPB	50.00	50.00	50.00	50.00	50.00	50.00
BC3 MW-2	8.57	BLQ	6.47	2.30	1.18	BLQ
BC3 MW-2 Duplicate	8.77	BLQ	6.31	2.21	1.16	BLQ
ESMP-3D	BLQ	ND	ND	ND	ND	ND
ESMP-3DD	ND	ND	ND	ND	ND	ND
BC3 MW-4	ND	ND	ND	ND	ND	ND
GC LAB BLANK, PPB	ND	ND	ND	ND	ND	ND
1 PPB	1.12	1.07	1.07	1.06	1.11	1.04

ND = None Detected; BLQ = Below Limit of Quantitation, 1 ppb; N/A = Not Analyzed

SampleName	1,3,5-TMB	1,2,4-TMB	1,2,3-TMB	1,2,4,5-Tetra	1,2,3,5-Tetra	1,2,3,4-Tetra	Fuel Carbon
10 PPB	10.11	10.33	10.32	10.48	10.51	10.52	N/A
QC, OBSERVED, PPB	49.81	51.06	48.74	44.41	48.88	48.83	N/A
QC, TRUE VALUE, PPB	50.00	50.00	50.00	50.00	50.00	50.00	N/A
BC3 MW-2	ND	9.01	5.41	1.36	1.74	2.36	97.10
BC3 MW-2 Duplicate	ND	8.77	5.19	1.74	2.00	2.81	95.56
ESMP-3D	ND	ND	ND	ND	ND	ND	BLQ
ESMP-3DD	ND	ND	ND	ND	ND	ND	ND
BC3 MW-4	ND	ND	ND	ND	ND	ND	ND
GC LAB BLANK, PPB	ND	ND	ND	ND	ND	ND	N/A
1 PPB	1.02	1.04	1.07	0.98	1.03	1.02	N/A

ND = None Detected; BLQ = Below Limit of Quantitation, 1 ppb; N/A = Not Analyzed

Ref: 95-DF40

July 28, 1995

Dr. Don Kampbell
R.S. Kerr Environmental Research Lab
U.S. Environmental Protection Agency
P.O. Box 1198
Ada, OK 74820

THRU: S.A. Vandegrift

Dear Don:

As requested in Service Request SF-1-137, GC/MS analysis for phenols and aliphatic/aromatic acids was done on one water sample from the Battle Creek site. Liquid-liquid extraction was done by Amy Zhao on July 20, 1995. The extracts were analyzed by GC/MS on July 26 - 26, 1995. RSKERL SOP 177 was used for the extraction, derivatization and GC/MS analysis of the samples.

Table I provides the concentrations of the aliphatic/aromatic acids found in Battle Creek sample, BC-3 MW-2 and quality assurance samples run at the same time as the samples. Please note that the level of benzoic acid determined in the check standard was 15 ppb higher than expected. This is a reoccuring problem due to the presence of benzoic acid in the derivatizing reagent.

Spike recoveries for each of the acids and phenols were determined in a 50 ppb spike of 100 ml of water blank. Recovery of the 50 ppb concentration was poor for low molecular weight aliphatic acids due to the poor extraction efficiencies of these acids from water. Higher molecular weight aliphatic and aromatic acids exhibit good recoveries.

Enclosed please find chromatograms of the pentafluorobenzyl derivatives for sample BC-3 MW-2. Within the range between scans 1750 and 2150, five major peaks are found with ions at m/z 143. This pattern of peaks was also found in samples from King Salmon (ESMW-8A) and Rickenbacken ANGB (Sample MW-5). A significantly different pattern of peaks with ions at m/z 143 were found in samples from Pope AFB (POMP12S, POMW1 and POMW121). Assuming that the ion at 143 is a carboxylate ion, these peaks could correspond to C_8 carboxylic acids, hydroxycyclohexylcarboxylic acids,

ManTech Environmental Research Services Corporation

R.S. Kerr Environmental Research Laboratory, P.O. Box 1198, 919 Kerr Research Drive
Ada, Oklahoma 74821-1198   405-436-8660   FAX 405-436-8501

hydroxyalkenyl carboxylic acids or ketoaliphatic acids. The compound class of these peaks will be determined as soon as the Tracer GC-FTIR becomes operational.

If you should have any questions, please feel free to contact me.

Sincerely,

Dennis D. Fine

xc: J.L. Seeley
     G.B. Smith
     R.L. Cosby

Table I. Quantitative Report and QC Data for Phenols and Aliphatic and Aromatic Acids (Service Request SF-1-227).

		Concentration ppb				
		BC-3 MW-2	Standard Derivatization Blank	Extraction Blank	50 ppb Extraction Recovery	10 ppb Check Standard
1	PROPANOIC ACID – PFB	N.F.	N.F.	***	5	11
2	2-METHYLPROPANOIC ACID – PFB	***	***	***	17	10
3	TRIMETHYL ACETIC ACID – PFB	N.F.	N.F.	***	42	11
4	BUTYRIC ACID – PFB	***	8	***	15	10
5	2-METHYLBUTYRIC ACID – PFB	***	***	***	38	9
6	3-METHYLBUTYRIC ACID – PFB	***	***	***	36	9
7	3,3-DIMETHYLBUTYRIC ACID – PFB	70	N.F.	***	51	10
8	PENTANOIC ACID – PFB	***	***	***	40	9
9	2,3-DIMETHYLBUTYRIC ACID – PFB	***	N.F.	***	48	10
10	2-ETHYLBUTYRIC ACID – PFB	***	N.F.	***	49	8
11	2-METHYLPENTANOIC ACID – PFB	N.F.	N.F.	***	50	7
12	3-METHYLPENTANOIC ACID – PFB	N.F.	***	N.F.	49	9
13	4-METHYLPENTANOIC ACID – PFB	***	N.F.	***	46	9
14	HEXANOIC ACID – PFB	***	***	7	52	8
15	2-METHYLHEXANOIC ACID – PFB	N.F.	N.F.	***	50	9
16	PHENOL – PFB	6	5	19	42	11
17	CYCLOPENTANECARBOXYLIC ACID – PFB	***	N.F.	***	42	10
18	5-METHYLHEXANOIC ACID – PFB	N.F.	N.F.	***	86	8
19	o-CRESOL – PFB	***	***	N.F.	49	9
20	2-ETHYLHEXANOIC ACID – PFB	131	***	***	51	5
21	HEPTANOIC ACID – PFB	***	***	7	51	10
22	m-CRESOL – PFB	5	***	N.F.	47	8
23	p-CRESOL – PFB	N.F.	***	***	48	8
24	1-CYCLOPENTENE-1-CARBOXYLIC ACID – PFB	N.F.	N.F.	***	40	9
25	o-ETHYLPHENOL – PFB	N.F.	N.F.	N.F.	49	9
26	CYCLOPENTANEACETIC ACID – PFB	***	N.F.	***	48	11
27	2,6-DIMETHYLPHENOL – PFB	N.F.	N.F.	N.F.	41	7
28	2,5-DIMETHYLPHENOL – PFB	N.F.	N.F.	***	48	8
29	CYCLOHEXANECARBOXYLIC ACID – PFB	***	N.F.	***	49	11
30	3-CYCLOHEXENE-1-CARBOXYLIC ACID – PFB	N.F.	N.F.	***	47	10
31	2,4-DIMETHYLPHENOL – PFB	N.F.	N.F.	N.F.	40	8
32	3,5-DIMETHYLPHENOL & M-ETHYLPHENOL – PFB	N.F.	N.F.	***	49	8
33	OCTANOIC ACID – PFB	***	***	9	53	10
34	2,3-DIMETHYLPHENOL – PFB	***	N.F.	***	50	8
35	p-ETHYLPHENOL – PFB	N.F.	N.F.	N.F.	49	8
36	BENZOIC ACID – PFB	17	13	7	47	25
37	3,4-DIMETHYLPHENOL – PFB	N.F.	N.F.	***	48	8
38	m-METHYLBENZOIC ACID – PFB	N.F.	N.F.	N.F.	41	10
39	1-CYCLOHEXENE-1-CARBOXYLIC ACID – PFB	N.F.	N.F.	***	48	10
40	CYCLOHEXANEACETIC ACID – PFB	***	N.F.	N.F.	48	10
41	2-PHENYLPROPANOIC ACID – PFB	***	N.F.	N.F.	48	11
42	o-METHYLBENZOIC ACID – PFB	***	***	***	50	11
43	PHENYLACETIC ACID – PFB	***	***	***	49	10
44	m-TOLYLACETIC ACID – PFB	6	N.F.	N.F.	45	11
45	o-TOLYLACETIC ACID – PFB	7	N.F.	6	48	10
46	2,6-DIMETHYLBENZOIC ACID – PFB	***	N.F.	***	51	11
47	p-TOLYLACETIC ACID – PFB	N.F.	N.F.	N.F.	49	11
48	p-METHYLBENZOIC ACID – PFB	***	N.F.	***	48	10
49	3-PHENYLPROPANOIC ACID – PFB	N.F.	N.F.	5	45	11
50	2,5-DIMETHYLBENZOIC ACID – PFB	5	N.F.	5	48	11
51	DECANOIC ACID – PFB	***	***	6	48	9
52	2,4-DIMETHYLBENZOIC ACID – PFB	N.F.	N.F.	***	49	9
53	3,5-DIMETHYLBENZOIC ACID – PFB	***	N.F.	***	49	10
54	2,3-DIMETHYLBENZOIC ACID – PFB	***	N.F.	***	49	9
55	4-ETHYLBENZOIC ACID – PFB	***	N.F.	***	49	11
56	2,4,6-TRIMETHYLBENZOIC ACID – PFB	7	N.F.	N.F.	52	11
57	3,4-DIMETHYLBENZOIC ACID – PFB	5	N.F.	N.F.	44	12
58	2,4,5-TRIMETHYLBENZOIC ACID – PFB	5	N.F.	N.F.	49	12

*** indicates concentration of extract was below lowest calibration standard (5 ppb).
N.F. indicates not found.

MANAGEMENT TECHNOLOGY

Ref: 95-JH50/vg

August 25, 1995

Dr. Don Kampbell
R.S. Kerr Environmental Research Lab
U.S. Environmental Protection Agency
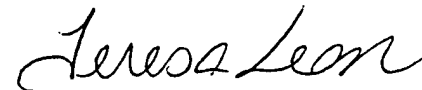P.O. Box 1198
Ada, OK 74820

THRU: S.A. Vandegrift

Dear Don:

Battle Creek

Find attached results for methane and ethene on samples received on June 20, 1995 and analyzed on July 26, 1995 under Service Request #SF-1-137. Samples were prepared and calculations were done as per RSKSOP-175. Analyses were performed as per RSKSOP-147.

If you have any questions, feel free to contact me.

Sincerely,

Jeff Hickerson

xc: R.L. Cosby
     J.L. Seeley
     G.B. Smith

ManTech Environmental Research Services Corporation

R.S. Kerr Environmental Research Laboratory, P.O. Box 1198, 919 Kerr Research Drive
Ada, Oklahoma 74821-1198   405-436-8660   FAX 405-436-8501

ANALYSIS PERFORMED 7-26-95

SAMPLE	METHANE	ETHENE
LAB BLANK	BLQ	ND
BC3MW-2	1.30	ND
BC3MW-4	0.003	ND
ESMP-3D	0.007	ND
ESMP-3DD	0.001	ND
" FIELD DUP	0.001	ND
" LAB DUP	0.001	ND
10 PPM CH4	10.00	NA
100 PPM CH4	100.05	NA
1000 PPM CH4	1000.20	NA
1% CH4	0.99	NA
10 % CH4	10.00	NA
10 PPM C2H4	NA	10.36
100 PPM C2H4	NA	99.96

LIMITS OF QUANTITATION

METHANE	ETHENE
0.001	0.003

SAMPLE UNITS ARE mg/L.
STANDARDS UNITS CORRESPOND
TO THE SAMPLE COLUMN.

BLQ DENOTES BELOW LIMIT OF QUANTITATION.
ND DENOTES NONE DETECTED.
NA DENOTES NOT ANALYZED.

Ref: 95-TL29/vg

July 27, 1995

Dr. Don Kampbell
R.S. Kerr Environmental Research Lab
U.S. Environmental Protection Agency
P.O. Box 1198
Ada, OK 74820

THRU: S.A. Vandegrift

Dear Don:

　　Attached are TOC results for a set of 4 liquid samples received by MERSC June 20, 1995 under Service Request #SF-1-137. Determinations were begun and completed July 26, 1995 using RSKSOP-102.

　　A known AQC sample was analyzed with your samples for quality control. If you have any questions concerning these results please feel free to contact me.

Sincerely,

Teresa Leon

Teresa Leon

xc:　R.L. Cosby
　　　J.L. Seeley
　　　G.B. Smith

ManTech Environmental Research Services Corporation

R.S. Kerr Environmental Research Laboratory, P.O. Box 1198, 919 Kerr Research Drive
Ada, Oklahoma 74821-1198   405-436-8660   FAX 405-436-8501

TOC FOR D●●PBELL (SF-1-137)

SAMPLE	MG/L OC
BC3MW-2	8.0
BC3MW-4	0.8
ESMP-3D	1.4
ESMP-3DD	0.9
ESMP-3DD F-DUP	1.2
WPO33-II	34.8 MG/L
	35.2 MG/L

TRUE VALUES: WPO33-II = 35.0 MG/L

Ref: 95-TH57/rc

June 22, 1995

Dr. Don Kampbell
R.S. Kerr Environmental Research Lab
U.S. Environmental Protection Agency
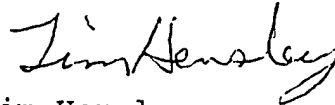Post Office Box 1198
Ada, OK 74820

THRU: S.A. Vandegrift

Dear Don:

    Attached are the results of 4 samples from Battle Creek
Michigan submitted to ManTech as part of S.R. # SF-1-137.   The
samples were received on June 20, 1995 and analyzed June 21, 1995.
The methods used for analysis were EPA Method 353.1 and Water's
Capillary Electrophoresis Method N-601. Quality assurance measures
performed on this set of samples included spikes, duplicates, known
AQC samples and blanks.

    If you have any questions concerning these results please feel
free to contact me.

                              Sincerely,

                              Tim Hensley

xc: R.L. Cosby
     G.B. Smith
     J.L. Seeley

ManTech Environmental Research Services Corporation

R.S. Kerr Environmental Research Laboratory, P.O. Box 1198. 919 Kerr Research Drive
Ada, Oklahoma 74821-1198   405-436-8660   FAX 405-436-8501

Sample	mg/l $NO_2^-(N) + NO_3^-(N)$	mg/l Cl^-	mg/l SO_4^{-2}
ESMP-3D	.94	1.16	7.95
ESMP-3D Dup	.95	1.11	7.85
ESMP-3DD	<.05	5.48	25.0
BC3MW-2	.69	1.58	10.1
BC3MW-4	<.05	5.36	23.0
Blank	<.05	<.5	<.5
AQC	.26	57.9	21.1
AQC T.V.	.27	59.2	22.0
Spike Recovery	98%	98%	98%

FIELD DATA
BATTLE CREEK, MICHIGAN

SAMPLE	DATE	REDOX MV	PH UNITS	CONDUCTIVITY	TOTAL ALK. AS CaCO3 MG/L	FERROUS IRON MG/L	HYDROGEN SULFIDE MG/L
BC3MW4	6-16-95	-60	7.6	504	224	O.5	<0.1
BC3MW2	6-16-95	-90	7.2	556	268	2.3	<O.1
ESMP-3D	6-16-95	160	7.5	491	230	<.05	------
ESMP-3DD	6-16-95	-130	7.3	545	243	2.8	<O.1

April 19, 1998 ← suspect 6/16/95   Suspicions correct
this is different
well casing   6/16/95
MH

Well	TOC ∇	Well Depth	Temp. °C	D.O. mg/l	Well casing
BC3MW-2	28.9'	42'	16.9	0.4	2 inch
BC3MW-4	29.2'	59'	14.7	0.3	2 inch
ESMP-3D	———		15.9	1.4	1 inch
ESMP-3DD	———		15.1	0.3	1 inch
ESMP-3S	No water				
ESMP-4S	No water				
ESMP-4D	No water				

MAN*AGEMENT*
TECH*NOLOGY*

Ref: 98/JAD28

May 5, 1998

Dr. Don Kampbell
National Risk Management Research Laboratory
Subsurface Protection and Remediation Division
U.S. Environmental Protection Agency
P.O. Box 1198
Ada, OK 74820

THRU: S.A. Vandegrift

Dear Don:

As requested in Service Request # SF-4-317, headspace GC/MS analysis of 42 water samples for chlorinated volatile organics from Wurstmith AFB was completed. The samples were received on April 23, 1998 and analyzed on April 27-29, 1998. RSKSOP-148 (Determination of Volatile Organic Compounds in Water by Automated Headspace Gas Chromatography/Mass Spectrometry (Saturn II Ion Trap Detector) was used for this analysis.

An internal standard calibration method was established for the 15 compounds. The standard curves were prepared from 1.0 to 4000 ppb. The lower calibration limits were 1.0 ppb.

If you should have any questions, please feel free to contact me.

Sincerely,

John Allen Daniel

xc: R.L. Cosby
    G.B. Smith
    D.D. Fine
    J.L. Seeley
    J.T. Wilson

ManTech Environmental Research Services Corporation

R.S. Kerr Environmental Research Laboratory, P.O. Box 1198, 919 Research Drive
Ada, Oklahoma 74821-1189   405-436-8660   FAX 405-436-8501

Ta●3. Quantitation Report for SI● SF-4-317 from Wurtsmith A●

Battle Creek

Concentration = ppb

	FT-ML-02 19.53'	FT-ML-02 20.5	FT-ML-02 20.5 Lab Dup	DC-3MW4	ESMP-4D	ESMP-4S	ESMP-2S	ESMP-2S Field Dup	ESMP-2D	ESMP-2DD
VINYL CHLORIDE	3.9	1.9	1.9	ND	ND	ND	ND	ND	ND	ND
1,1-DICHLOROETHENE	---	---	---	ND	ND	ND	ND	ND	ND	ND
T-1,2-DICHLOROETHENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,1-DICHLOROETHANE	---	---	ND	ND	ND	ND	ND	ND	ND	ND
C-1,2-DICHLOROETHENE	1370	638	618	ND	ND	ND	ND	ND	ND	ND
CHLOROFORM	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,1,1-TRICHLOROETHANE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
CARBON TETRACHLORIDE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,2-DICHLOROETHANE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
TRICHLOROETHENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
TETRACHLOROETHENE	ND	ND	ND	ND	ND	ND	---	ND	ND	ND
CHLOROBENZENE	2.0	12.8	12.9	ND	ND	ND	ND	ND	ND	ND
1,3-DICHLOROBENZENE	6.5	9.9	9.8	ND	ND	ND	ND	ND	ND	ND
1,4-DICHLOROBENZENE	12.0	10.0	9.9	ND	ND	ND	ND	ND	ND	ND
1,2-DICHLOROBENZENE	71.5	43.7	43.4	ND	ND	ND	ND	ND	ND	ND

	ESMP-2DD Lab Dup	QC0427A 20 ppb	QC0427B 200 ppb	QC0427C 200 ppb	QC0427D 20 ppb	QC0427E 200 ppb	QC0427F 20 ppb	QC0427G 200 ppb	QC0427H 20 ppb	BL0427C
VINYL CHLORIDE	ND	21.1	190	187	18.9	186	20.5	193	18.6	ND
1,1-DICHLOROETHENE	ND	20.3	208	193	19.8	198	19.6	199	18.7	ND
T-1,2-DICHLOROETHENE	ND	21.0	207	198	20.8	197	19.8	203	19.0	ND
1,1-DICHLOROETHANE	ND	20.9	207	205	20.3	207	21.0	212	19.5	ND
C-1,2-DICHLOROETHENE	ND	20.6	208	209	20.2	205	21.4	213	19.7	ND
CHLOROFORM	ND	19.9	203	208	20.0	201	20.7	207	19.4	ND
1,1,1-TRICHLOROETHANE	ND	20.7	200	190	19.8	199	20.1	194	19.0	ND
CARBON TETRACHLORIDE	ND	22.4	220	204	20.9	212	21.3	201	19.8	ND
1,2-DICHLOROETHANE	ND	19.7	215	200	18.8	207	20.6	221	17.9	ND
TRICHLOROETHENE	ND	20.4	219	205	20.8	208	19.5	220	20.1	ND
TETRACHLOROETHENE	ND	22.7	212	204	21.0	206	20.2	198	19.3	ND
CHLOROBENZENE	ND	20.6	205	214	21.0	210	21.3	217	19.2	ND
1,3-DICHLOROBENZENE	ND	20.5	211	208	20.6	210	20.5	212	19.2	ND
1,4-DICHLOROBENZENE	ND	20.7	213	206	20.3	211	21.5	217	20.4	ND
1,2-DICHLOROBENZENE	ND	20.9	215	219	20.7	220	21.5	226	20.3	ND

ND = None Detected   ---- = Below Calibration Limit(1.0 ppb)   Dup = Duplicate   QC = Quality Control Std

BATTLE CREEK ANG - 1998

Sample	Date	pH su	Fe++ mg/L	Alkalinity mg/L	Carbon Dioxide mg/L	Sulfide mg/L	Manganese mg/L
BC3-MW4	4-20-98	7.2	<.1	220	15	<.1	<.1
ESMP-4D	4-20-98	7.8	<.1	240	45	<.1	<.1
ESMP-4S	Dry Well						
ESMP-2S	4-20-98	7.4	0.1	300	100	<.1	<.1
ESMP-2D	4-20-98	7.3	0.1	320	55	<.1	<.1
ESMP-2DD	4-20-98	7.3	3.0	360	45	<.1	<.1
*Well BC3-MW2 was being sparged							

Site was being sparged so didn't measure D.O. ad RedOx.

No geochem data. however, analytical data is available for VOCs & methane, ethane, & ethe

MJP

Dr. Don Kampbell
National Risk Management Research Laboratory
Subsurface Protection and Remediation Division
U.S. Environmental Protection Agency
P.O. Box 1198
Ada, OK 74820

THRU: Steve Vandegrift SV

Dear Don:

Please find attached the analytical results for Service Request SF-4-317 from Wurtsmith AFB, MI and Battlecreek ANG, MI requesting the analysis of aqueous samples to be analyzed for MTBE, BTEXXX and TMBs. The 41 samples, in duplicate, were received in capped, 40 mL VOA vials on April 22, 1998. The samples were analyzed on April 27 and 28, 1998. All samples were acquired using the Millennium data system. A 4 point (1-1000 ppb) external calibration curve was used to determine the concentration for all compounds.

RSKSOP-122 "Analysis of Volatile Aromatic Hydrocarbons with Separation of Xylene Isomers by Purge & Trap Gas Chromatography" was used for these analyses. Auto-sampling was performed using a Dynatech Precision autosampler system in line with a Tekmar LSC 2000 concentrator.

Sincerely,

Mark Blankenship

xc: R.L. Cosby
    J.L. Seeley
    G.B. Smith

ManTech Environmental Research Services Corporation

R.S. Kerr Environmental Research Laboratory, P.O. Box 1198, 919 Research Drive
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SAMPLE NAME	MTBE	BENZENE	TOLUENE	ETHYLBENZENE	p-XYLENE	m-XYLENE	o-XYLENE	1,3,5-TMB	1,2,4 TMB	1,2,3 TMB
1 PPB STD	1.0	1.1	1.3	1.1	1.4	1.4	1.4	1.3	1.5	1.1
QC, OBSERVED, 20 PPB	17.0	18.4	18.1	17.6	18.6	18.0	18.1	18.5	18.4	17.1
QC, TRUE VALUE, 20 PPB	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0
GC LAB BLANK	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
MP-2D wirT smith	ND	ND	ND	BLQ	1.0	1.7	ND	ND	1.2	BLQ
MP-5S	BLQ	237.9	BLQ	166.6	193.9	360.8	1.0	25.1	91.3	57.7
MP-21D	ND	1.7	ND	3.3	5.1	5.5	ND	ND	8.2	3.0
MW-1-SS-42	ND	BLQ	66.8	26.1	27.4	68.4	45.9	6.7	19.8	11.3
FT-ML-01-19-20 ft wirtNsmith	17.6	715.1	48.2	564.4	454.0	1362.0	54.3	177.2	588.8	286.3
BC3-MW-4 Battle Creek	ND	BLQ	ND	2.8	2.8	7.7	BLQ	1.6	5.1	2.5
MP-1D wirismith	ND	2.6	ND	ND	ND	ND	ND	ND	ND	ND
MP-1S	4.8	5.1	ND	449.3	373.1	983.0	2.7	110.1	334.0	198.8
MP-3S	ND	BLQ	ND	BLQ	BLQ	BLQ	ND	ND	ND	ND
10 PPB STD	8.8	9.5	9.2	9.4	9.2	9.1	9.0	9.4	9.0	9.5
MP-5D	ND	BLQ	ND	ND	ND	BLQ	ND	ND	ND	ND
MP-5D LAB DUPLICATE	ND	BLQ	ND	ND	ND	ND	ND	ND	ND	ND
MP-6D	ND	BLQ	ND	BLQ	BLQ	BLQ	ND	ND	ND	ND
MP-6S	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
MP-7S	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
MP-8D	ND	BLQ	ND	ND	ND	ND	ND	ND	ND	ND
ESMP-2S Battle Creek	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
ESMP-2D Battle Creek	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
ESMP-2DD Battle Creek	ND	ND	ND	ND	ND	BLQ	ND	ND	ND	ND
100 PPB STD	80.8	90.4	89.1	91.4	91.1	90.3	89.4	93.7	90.7	90.4
GC LAB BLANK	ND	ND	ND	ND	BLQ	ND	ND	ND	ND	ND
FT-ML-02-18.5 ft wirismith	BLQ	17.2	BLQ	61.8	58.5	162.7	2.9	17.5	58.6	34.0
FT-ML-01-26.3 ft	ND	BLQ	ND	BLQ	BLQ	1.2	ND	ND	1.2	BLQ
FT-ML-01-26.3 ft LAB DUPLICATE	ND	BLQ	ND	2.3	BLQ	1.2	ND	ND	1.4	BLQ
FT-ML-01-16.9-17.9 ft	ND	34.8	1.4	12.6	15.7	45.1	4.7	5.1	13.3	8.6
FT-ML-02-20.5 ft	ND	10.6	BLQ	13.6	12.3	35.4	1.6	5.2	16.2	9.2
FT-ML-01-21.5-22.5 ft	ND	2.0	BLQ	6.9	5.6	14.0	BLQ	2.0	6.3	3.1
FT-ML-01-23.5-24.5 ft	ND	BLQ	ND	4.4	3.1	5.3	BLQ	1.9	6.7	3.0
FT-ML-02-19.53 ft	ND	4.5	ND	9.6	7.8	22.5	1.1	2.0	6.8	3.2

ND = None Detected; BLQ = Below Limit of Quantitation, 1ppb

MANAGEMENT TECHNOLOGY

Dr. Don Kampbell
National Risk Management Research Laboratory
Subsurface Protection & Remediation Division
U.S. Environmental Protection Agency
P.O. Box 1198
Ada, OK 74821-1198

THRU: S.A. Vandegrift $\mathcal{SV}$

Dear Don:

Attached are the results of 5 Battlecreek, MI, samples submitted to MERSC as part of
S.R. # SF-4-317. The samples were received 4/22/98 and analyzed 4/23 and 4/24. The methods
used for analysis were Lachat FIA methods 10-107-06-1-A for ammonia and 10-107-04-2-A for
nitrite & nitrate, and Waters Capillary Electrophoresis method N-601 for chloride and sulfate.

Quality assurance measures performed on this set of samples included spikes, duplicates,
known AQC samples, and blanks.

If you have any questions concerning these results, please feel free to contact us.

Sincerely,

Lynda Pennington

Brad Scroggins

xc: R.L Cosby
    J.L. Seeley
    G.B. Smith

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SAMPLE	mg/L NO2+NO3	mg/L NH3	mg/L Chloride	mg/L Sulfate
BC-3-MW4	0.20	<0.1	6.77	20
BC-3-MW4 DUP	0.20	<0.1	6.75	19.9
ESMP-4D	1.0	<0.1	22.3	9.63
ESMP-2S	2.09	<0.1	77.5	11.8
ESMP-2D	1.1	<0.1	1.43	13
ESMP-2DD	<0.1	<0.1	15.2	42
BLANK	<0.1	<0.1	<.1	<.1
AQC	0.60	0.23	32.8	43.3
AQC TRUE VALUE	0.62	0.26	34.8	44
SPIKE RECOVERY	105%	97%	102%	99%

Battle Creek ANG - April 1998

Sample	Temp °C	Cond. µS/cm	D.O. mg/L	Redox mv	∇ ft TOC
ESMW4-S	Low yield well - only VOA & D.O. samples taken				25.7
ESMW2-S	Low yield well - dribble sample				26.9
BC3-MW4	12.3	318	1.0	+107	28.9
ESMW-4D	12.8	650	0.9	+142	25.6
ESMW-2D	13.2	604	9.7	+221	26.9
ESMP-2DD	13.0	584	0.7	-123	26.9

✱ Note - well BC3-MW2 was being
    actively sparged.

SF-4-317 05/06/98
Battle Creek

Sample	Methane	Ethylene	Ethane
100ppm CH4	92.6	**	**
100ppm C2H4	**	107.3	**
100ppm C2H6	**	**	98.0
HPHe	**	**	**
Lab Blank	**	**	**
BC-3-MW4	**	**	**
ESMP-4S	**	**	**
ESMP-4D	0.004	**	**
ESMP-3S	**	**	**
ESMP-2D	**	**	**
ESMP-2DD	0.002	**	**
ESMP-2DD Field Dup	0.002	**	**
10ppm C2H6	**	**	11.4
100ppm CH4	97.8	**	**
100ppm C2H4	**	106.6	**
100ppm C2H6	**	**	105.9

Lower Limit of Quantitation

	0.001	0.003	0.002

Units for the samples are mg/L dissolved in water.
Units for the standards are parts per million.

denotes None Detected.
denotes Below Limit of Quantitation.